Basis of Design Report

Asotin IMW Restoration: RCO Project# 23-1036

Sponsor:
Aaron Penvose, Trout Unlimited

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Summary

The Asotin Creek Intensively Monitored Watershed (IMW) project began in 2008 and is ongoing. The Asotin IMW is a watershed-scale experiment testing the effectiveness of adding large woody debris (LWD) to restore physical and biological processes that create and sustain complex and healthy stream habitats and fish populations. All the restoration implemented to date in the Asotin IMW has been funded by the Salmon Recovery Funding Board. The Asotin IMW is one of two IMWs studying low-tech process-based restoration (LTPBR) techniques. Asotin is testing post-assisted log structures (PALS) and installed 654 structures across 8.7 miles between 2012-2016. The Bridge Creek IMW, in Oregon tested the effectiveness of installing 120 beaver dam analogues (BDAs). These LTPBR approaches have both demonstrated that they can increase habitat complexity and floodplain connection and both IMWs have shown significant increases in juvenile steelhead. However, Bridge IMW showed that the combination of installing BDAs and an increase in natural beaver dams increased floodplain inundation ~200% and juvenile steelhead production 170% compared to the Asotin IMW which has only increased floodplain connection 5-25% and juvenile steelhead production 20-50%. In part, because of these IMWs LTPBR restoration actions are becoming very popular and are implemented across the Pacific Northwest and beyond. As such, the Asotin and Bridge Creek IMWs can provide important insights into management and conservation questions related to LTPBR approaches.

To further expand our understanding of LTPBR effectiveness in Asotin Creek, we are proposing to open confining berms scattered throughout the treatment areas of the IMW study area and add additional restoration structures to increase the total length restored from 8.7 miles to almost 15 miles (i.e., 40 to 66% of the study area) with 7.5 miles (i.e., 33% of the study area) maintained in control sections. This will lead to more side-channel and floodplain connection, increased habitat for juvenile steelhead, and potentially a larger response in steelhead abundance and production. This proposal maintains the experimental soundness of the Asotin Creek IMW, increases the restored area within the IMW by 6 miles, potentially increases the area of available habitat for rearing and spawning steelhead by 2.5-3.0 miles and 10-15 acres, could benefit other species such as chinook, bull trout, and pacific lamprey in Asotin Creek, and will provide critical management guidance for increasing popular LTPBR methods and help to answer questions such as how effective LWD additions can be at increasing the steelhead capacity of wadable streams, how much maintenance is required to maximize habitat responses, and how long will it take to promote sustainable riverscape processes.

Table of Contents

List of Figures

List of Tables

Basis of Design Report

Asotin IMW Restoration: RCO Project# 23-1036

Introduction

The Asotin Creek Intensively Monitored Watershed (IMW) is an ongoing, long-term watershed-scale experiment in southeast Washington, established in 2008 to test the effectiveness of large woody debris (LWD) additions at improving stream complexity, pool frequency, side-channel and floodplain connection, and riparian health (Appendix A). Asotin Creek is managed as a wild steelhead refuge, and Snake River summer-run steelhead are the focal species of the IMW. Stream habitat quality in Asotin Creek and tributaries was found to be limiting steelhead populations due to a lack on instream complexity, large woody debris, deep pools, off-channel, side-channel, and floodplain connection (SRSRB 2011, Bennett and Bouwes 2009, Wheaton et al. 2012).

Intensively Monitored Watersheds and Low-tech Process-based Restoration

Asotin Creek IMW is one of only two IMWs in the Pacific Northwest that is focused on testing Low-tech Process-based restoration (LTPBR) approaches (Bilby et al. 2005, Bennett et al. 2016, Haskell et al. 2019, Hillman et al, 2019, Wheaton et al. 2019, Bilby et al. 2023 - DRAFT). The other IMW testing LTPBR is the Bridge Creek IMW which is assessing the effectiveness of Beaver Dam Analogues (BDAs). LTPBR approaches build on the literature of process-based and ecological restoration from the 1990's that stressed a movement away from form-based restoration actions towards restoring the "normative rates and magnitudes of physical and biological processes" (Beechie et al. 2010, Palmer et al. 2005). The Bridge and Asotin Creek IMWs are providing critical monitoring and analysis of the effectiveness of these LTPBR methods at a time when interest and implementation is growing rapidly throughout North America. LTPBR methods work best in wadable streams where risks and constraints are limited, and much of the valley bottom is available to reconnect. LTPBR approaches are based on riverscape principles that rivers need space and that LWD or beaver dams are often a critical component of streams that forces complexity and lateral, longitudinal, and vertical connectivity of the stream channel, floodplain, and groundwater (Wheaton et al. 2019; Appendix B; LTPBR Manual). LTPBR also relies on restoration principles, especially to "let the system do the work" and "defer decision making to the system", and "strength in numbers". These principles rely less on trying to be overly precise or focus on stability of structures, but instead add high numbers of hand-built structures with simple techniques, and allow the system (i.e., high flows or beavers) to cause erosion, deposition, and floodplain connection. The limited design criteria and less focus on stability defers decision making to the system on how the structures interact with flows, sometimes fail, or move, and lead to a more dynamic system with increased hydraulic and geomorphic complexity. LTPBR approaches, although often relying on hand-built structures, does not exclude mechanical intervention, provided it adheres to the general riverscape and restoration principles.

Study Area

The IMW is implemented in three Asotin Creek tributaries: Charley Creek, North Fork Asotin Creek (North Fork), and South Fork Asotin Creek (South Fork; hereafter referred to together as "study streams"; Appendix C). Intensive monitoring of water temperature, discharge, habitat, and juvenile steelhead has been ongoing in the study streams since 2008 (Bennett et al. 2021). Pre-restoration monitoring was conducted from 2008-2012. Then one 2.5-mile-long section in each study stream was restored using post-assisted log structures (PALS) which were developed in Asotin as part of a growing "low-tech process-based" restoration approach (Wheaton et al. 2012). An additional 1.5 miles of South Fork was restored in 2016 to extend one treatment to ~ 4 miles. Between 2012-2016, 8.7 miles of the study streams were treated while 14 miles were maintained as controls (i.e., ~40% of the study area is treated; Appendix C).

Progress and Challenges

To date, the Asotin Creek IMW has demonstrated significant increases in LWD and log jam frequency (193-962% increase), geomorphic complexity (23-110%), pool frequency (22-58%), abundance of juvenile steelhead (15-31%), and an increase in juvenile migrants (30-77%) in treatment compared to control sections across the three study streams (Bennett et al. 2021). These increases were initiated by the initial treatments, but also increased over time as we conducted maintenance and enhancement (i.e., increasing LWD density and adding whole trees) on the existing treatments. The habitat and fish responses were mostly attributed to increased complexity within the existing channel and with only small increases in off-channel, side-channel, and floodplain connection (~5-25% increase – we are still evaluating this metric). It has proven difficult to widen and aggrade treatment channels, and connect side-channel and floodplain habitats despite using PALS to try and force bank erosion, overbank flow, and channel widening. The banks are armored by dense alder roots and in many places old berms composed of large gravel and cobbles are preventing overbank flow and limiting the streams access to side-channels and floodplain areas.

Goals

The intent of the ***proposed project*** is to continue to implement the adaptive management plan of the IMW, identify and remove portions of confining berms that are preventing greater side-channel and floodplain connection, and restore an additional 5-6 miles of the study streams, while maintaining experimental controls in each stream (Wheaton et al. 2012, Bouwes et al. 2016a).

The goals of the project are to increase the restoration footprint of the IMW (from ~40% treated to 66% of the IMW study area treated) and significantly increase the amount of side-channel and floodplain connection. This is expected to increase the production and productivity of juvenile steelhead and the Asotin IMW is uniquely suited to detect habitat and populations changes, document the effectiveness, provide lessons learned, and management implications regarding this increasingly popular low-tech process-based restoration approach. We also can contrast these results with the Bridge Creek IMW which large increases in floodplain connection and juvenile steelhead production to better understand how the effectiveness of LWD compares to natural and simulated beaver dams (Bouwes et al. 2016b).

Objectives

The project objectives are to:

- Identify confining berms for potential opening in all three study streams
- Rank the berms based on maximizing side-channel and floodplain connection
- Use a mini-excavator or other suitable machine to open holes in 20-30 key confining berms (not complete removal)
- Install a combination of 175-250 post-assisted log structures (PALS), 175-250 whole trees, and 20-30 beaver dam analogues (BDAs) in three sections of the IMW (section 3 of Charley Creek, and section 2 of North Fork, and the lower 1.25 mi of section 1 of the South Fork, totaling 6 miles of treatment (see Appendix C for locations)
- Reconnect 10-15 acres of new floodplain, reconnect 2.0-3.0 miles of side-channels, and create or enhance 100-125 new pools

Site Characteristics

Watershed Conditions

The Asotin Creek Watershed area has several distinguishing features that have a large influence on river character and the potential to restore fish habitat. First, the region is dominated by long, hot summers and annual precipitation is low (< 20”) in all but the highest elevations (<40”) in the Blue Mountains. Watersheds are short and steep, with streams that generally have narrow valleys and discontinuous or patchy floodplain areas. In streams with headwaters in the Blue Mountains (e.g., the three IMW study streams), the hydrologic regime is snow-rain dominated and the flows are more consistent.

Southeast Washington has some of the most erosion prone soils in the state and soil erosion was a significant problem prior to the 1990s (ACCD 1995). Intensive agriculture on loess soils with a high erosion potential led to an over-supply of fine sediment into streams that severely degraded spawning habitat. Intensive logging in the headwaters, grazing throughout the watershed, removal of mature riparian forests, and numerous diversion dams for irrigation also led to degradation of fish habitat and rapid decline or complete extirpation of fish populations. Several large floods that happened every 10-20 years in the last century exacerbated the impact on channel, riparian, and floodplain conditions (Bennett et al. 2018). In 1995, a community led Model Watershed Plan was developed and in the subsequent 20 years restoration projects were implemented to improve upland and stream conditions (ACCD 1995). In the past common limiting factors on fish productivity in Asotin Creek include channel stability, sediment supply, flow, habitat diversity, temperature, and key habitat quantity. Reduction in sediment delivery and increased riparian protection and enhancement (i.e., planting and fencing) since the Model Watershed Plan was implemented have led to improvements in stream conditions (i.e., establishment of riparian vegetation, decreased sediment discharge from agriculture, and decreases in stream temperature). However, lack LWD, habitat complexity, and side-channel and floodplain access continue to limit fish productivity.

In the IMW study area riparian areas are generally recovering, are in poor-moderate condition, and consist of dense stands of young alder, some cottonwood, and willows (Wheaton et al. 2012, Bennett et al. 2018). Large Douglas-fir and Ponderosa pine grow near the stream of alluvial fans and hillslopes and can naturally recruit into the stream. A large wildfire in 2021 burned significant portions of the IMW study area and upper watersheds of the three study streams (Appendix D). A preliminary assessment by the Forest Service concluded that there was minimal risk or damage directly to the streams (Zapkora 2021). However, large numbers of dead trees are now falling into and near the stream that could be utilized for further restoration efforts. The fire burnt patches of riparian area in the IMW study area, but was most intense in upland forests and riparian areas in the upper watershed.

IMW Study Area

The IMW study area is on WDFW land managed as the Asotin Wildlife Management Area (Appendix E). The Wildlife Management Area is managed for wildlife resources, hunting, and recreation and as such has limited infrastructure or risk related to stream restoration. Upstream of the study area is land managed by the USFS. Downstream of the IMW study area is the mainstem of Asotin Creek with small farms and cattle operations. Most of the IMW study area was determined to be in poor to moderate function (i.e., the frequency and type of geomorphic units in a reach type were often below what would be expected in a properly functioning reach; Bennett et al. 2018). Reaches with limited geomorphic function were often due to low habitat diversity, lack of LWD, simplified channel planforms, and infrequent overbank flow. Riparian conditions have recovered well from historic disturbances but still have limited function often due to reduced extent of riparian habitat and young riparian canopy that do not produce much LWD that can enter the stream. Discontinuous and patchy historic berms and high banks are present in portions of all three study streams and are limiting side-channel and floodplain connection. Extensive geomorphic and riparian analysis and condition assessments are available in the Asotin Creek Restoration Plan (Wheaton et al. 2012) and the Asotin County Geomorphic Assessment (Bennett et al. 2018).

The management staff of the WDFW Asotin Wildlife Management Area have supported the IMW by allowing access to the land for monitoring and restoration, and by allowing harvesting of woody material on site to construct PALS and log jams. The WDFW also supplies important steelhead population data via a Bonneville Power Admiration funded fish-in fish-out project on the lower Asotin Creek where juvenile and adult steelhead are monitored annually migrating in and out of Asotin Creek. Fish are PIT tagged by WDFW staff and can be tracked entering and leaving the IMW study streams using arrays that can detect the tags. An IMW monitoring crew also PIT tags juvenile steelhead to assess abundance, growth, survival, production, and productivity in treatment (i.e., restored) and control sections.

Reach Characteristics

The IMW study area is dominated by reach types that are naturally confined or partly confined by the valley walls, and streams often run along steep bedrock cliffs. North Fork Asotin Creek is the largest stream and Charley Creek is the smallest (Table 1). Valley widths rarely exceed 300’ in North Fork Asotin and are usually <100’ in South Fork Asotin and Charley Creek. The most common reach types in the IMW study area are characterized by a single channel, low sinuosity, moderate to high gradient (1.5-3.5%), and long planar features (e.g., runs and rapids; Table 1). Floodplains are patchy or discontinuous and most pools are often forced by bars or large woody debris (LWD). Multiple channels can exist, but they are usually forced by wood. Wandering gravel bed reaches that have multiple channels and wider floodplains are mostly restricted to the North Fork Asotin Creek.

Table 1. Summary characteristics of the three Intensively Monitored Watershed study streams.

Stream	Basin Area (acres)	Bankfull width (ft)	Gradient (%)	Average Discharge (cfs)	Average Peak Discharge (cfs)
Charley	14,330	15	3.0	9.5	125
North Fork	40,800	32	1.7	60.0	700
South Fork	25,700	21	2.6	11.5	250

Flow and Sediment Regimes

The lower portions of the IMW study area is within semi-arid climate with most of the area receiving less than 19” of precipitation annually. As such the flow regime in the study area is a snow-rain dominated flow regime whereas the headwaters that feed the IMW study streams are snowmelt dominated with headwaters in the Blue Mountains. Springs are abundant especially in Charley Creek which has the coolest summer stream temperatures of the study streams. Average discharge ranges from 9.5-60 cfs with peak flows averaging 125-700 cfs (Table 1).

The range of hydrologic regimes across Asotin Creek are expected to change under predicted climate change scenarios. Higher maximum and minimum temperatures, higher intensity precipitation events, increased frequency of extreme events, and a less reliable snowpack are all expected. As such, the hydrologic regime in the IMW study streams is predicted to shift from snow-rain dominated to rain-dominated, which are where a significant portion of steelhead spawning and rearing takes place.

There are two main sources of sediment in the IMW study area: fine-grained loess (wind-blown silts), which dominate the basalt plateaus, and weathering of bedrock (primarily basalts from the CRBG) producing relatively coarse boulders, cobbles, and gravels. Because of the steep gradient and planar dominated geomorphology of the IMW study streams, loess soils are mostly washed downstream leaving a very coarse stream bed dominated by cobbles and gravels. There is also regular input of more angular colluvium from the steep valley walls. Due to the low frequency of LWD and the planar nature of the streams, sediment sorting is limited and there are few bars or off-channel areas with fine grained substrate.

Table 2. Mean substrate distribution based on standard Wollman pebble counts (Wolman 1954) from Asotin Creek Intensively Monitored Watershed project: 2011-2016.

Stream Name	Location	D^{50} (inches)	%Fines < 0.24 (inches)
Charley Creek	Lower 7 miles	1.9	28.0
North Fork Asotin	Lower 7 miles	2.9	8.8
South Fork Asotin	Lower 7 miles	2.5	10.2

Constraints, Maintenance, and Challenges

The Asotin Wildlife Management Area and Asotin Creek Watershed are an ideal area to implement the IMW due to the limited infrastructure and risks (i.e., most of the historic floodplain could be connected without impacting roads or other infrastructure), the study streams provide a wide range of stream types to test the effectiveness of LWD additions, the system is a wild steelhead refuge so there is limited hatchery influence (i.e., so increases in fish abundance can more easily be linked to restoration rather than hatchery supplementation), and the limiting factors are clearly identified and restoration processes needed to reach sustainability are understood (i.e., improve instream complexity and overbank flows, which will lead to increased riparian function and extent, and eventually sustained LWD recruitment).

Since 2016, we have implemented maintenance and enhancement of the original 8.7 miles of restoration treatments in the study stream as per our adaptive management plan. We have rebuilt some structures that washed out, added posts and wood to other structures that had lost wood, and increasingly we have felled live and dead alder, pine, and Douglas-fir in or near the floodplain to increase the wood loading and force greater hydraulic and geomorphic complexity, and side-channel and floodplain connection. This is in line with the basic principles of low-tech process-based restoration, whereby add wood to the streams, monitor the responses, and if the responses are not meeting the expected outcomes (i.e., high complexity and greater lateral connection) we push the system further by adding more wood. This approach is letting the system do much of the work (i.e., erosion and deposition) and using the minimal amount of effort to reach the project goals. To date, it has become clear that although we have documented large increases in LWD frequency and habitat complexity, connection of historic side-channels and floodplain connection has been more difficult. Hence, we are proposing to use targeted berm removal instead of erosion caused by structure placement, to increase side-channel and floodplain connection.

Alternatives Assessment and Selection

Based on the successes so far in the IMW, the LTPBR approach appears to have a high potential to increase learning of restoration effectiveness, availability and quality of fish habitat, and lead to increased production and productivity of wild steelhead. It is unclear how long it will take for this restoration project to become self-sustaining, but it is a key goal of the IMW to assess this very question. It is clear now after decades of restoration across the Pacific Northwest that restoration is not and cannot be a "one and done" approach, and that maintenance is the only way to promote self-sustaining systems (Lininger and Hilton 2022, Bilby et al. 2023). We considered two alternatives to the proposed LTPBR actions.

Alternative 1 – Do nothing different

In Alternative 1, we could continue to conduct maintenance on the existing restoration treatments as we have since 2016. This is a reasonable alternative as we have already demonstrated significant increases in LWD frequency which have been linked to changes in hydraulic complexity, which lead to increases in geomorphic complexity, and ultimately to moderate increases in juvenile abundance and productivity (i.e., more smolts leaving treatment versus control areas). We have also seen modest increases in side-channel and floodplain connection. However, what Alternative 1 lacks is the ability to test the hypothesis that greater side-channel and floodplain connection would lead to higher increases in fish abundance and productivity. This would be a significant accomplishment for the IMW and provide greater confidence to the restoration community that LTPBR methods can be very effective.

Alternative 2 – Stage 0

In Alternative 2, we could use a Stage 0 approach where the berms and confining features in the floodplain could be "reset" to a common elevation, wood could be added, and the system left to re-establish an anastomosing plane form (Powers et al. 2018). This alternative is process-based but certainly not low-tech. This would not be in step with the approach the IMW had taken from the beginning which was to test LTPBR approaches. This alternative would also be highly disruptive to the extensive riparian areas already established. This would not expand the IMWs ability to test LTPBR but limit it to provide any more learning that has already been accomplished to date. It is also not necessarily an appropriate approach in these streams as they are in confined and partly confined valleys and likely did not support anastomosing plane forms historically. Another research goal of the IMW will be to better define the reference conditions of these confined and partly confined Columbia Plateau streams to aid in better defining restoration goals.

Preferred Approach

We propose to continue to conduct maintenance, remove some confining features (i.e., berms), and restore other experimental sections with low-tech process-based approaches. This will lead to continued learning from the Asotin IMW and restore critical rearing and spawning habitat for ESA listed steelhead. This proposal is a natural next step in the IMW adaptive management plan and is completely consistent with the ***staircase experimental design*** we developed (Bouwes et al. 2016a, Loughlin et al. 2021). The IMW has already demonstrated tangible benefits from the implementation of PALS and the continued maintenance and enhancement (i.e., additions of trees and key pieces) of the treatments at both increasing LWD frequency, habitat complexity, and juvenile steelhead abundance (Wall et al. 2016, Bennett et al. 2021). There is also continued support for the IMW at both the local and state level. The Asotin and Bridge IMWs are the only IMWs focusing on testing the effectiveness of low-tech process-based restoration and both IMWs have already been successful at contributing to a greater understanding of LTPBR approaches (Bennett et al. 2016, Bouwes et al. 2016b, Wheaton et al. 2019, Wall et al. 2016, 2017).

Process-based approaches hope to restore the normative rates and magnitudes of physical, biological, and chemical processes that will sustain healthy riverscapes and the populations that depend on them (Beechie et al. 2010, Wheaton et al. 2019). LTPBR approaches represent a potential cost-effective way to add LWD to streams to mimic, promote, and eventually sustain natural wood regimes of streams. It is now clear that any restoration project that has the goal of restoring the natural wood regime will require multiple treatments and recovery of mature riparian forests. This is likely to take decades if not centuries (Wohl et al. 2019, Lininger and Hilton 2022, Pess et al. 2022). LTPBR offers a potential cost-effective way to help restore sustainable and resilient riverscapes and the Asotin IMW is setup well to help determine how long, how many treatments, and how much will it cost to attain sustainability.

Landownership and Infrastructure

The proposed project is within the Asotin Creek IMW study area in Asotin Creek (Appendix A, C). The IMW is within the lower 7.5 miles of three tributaries to Asotin Creek: Charley, North Fork, and South Fork Asotin Creeks. All the proposed restoration areas are on WDFW land within the Asotin Wildlife Management Area (Appendix E – Landownership). The remaining control sections are all on USFS land in the upper section of each study stream. There are county gravel roads along the lower portion of North Fork and South Fork Asotin Creeks, and the mid and upper portions are accessed by an old two-track road (Appendix F). The entire length of Charley Creek is accessed by a two-track dirt road. There is very little infrastructure in the IMW area except for two road crossings with high-clearance bridges (>12 feet clearance), one road crossing with a cement box culvert, a private house at the mouth of Charley Creek, and WDFW storage facilities at North Fork and South Fork Creeks (Appendix F). There is little risk to any of the road crossings or buildings in the IMW study area by the proposed restoration.

Project Elements

The project consists of identifying and opening confining berms, additional treatments of PALS, trees, and BDAs, and maintenance and enhancement of existing treatments.

Identification and Opening of Confining Berms

A goal of the IMW was to promote more overbank flow and connect historic side-channels and floodplain areas. The lack of LWD and channelized nature of the study streams limits overbank flow. There are also numerous old berms and high banks that limit ability of the streams to connect to the existing side-channels and floodplain. We hypothesized that we could use PALS to widen and aggrade channels and/or cause avulsions that could break down banks and confining features (berms). This has proved difficult due to the height of the berms and the dense alder roots that limit bank erosion. We propose to identify and open berms using small rubber tracked excavators and strategically placing PALS and log jams to reconnect side-channels and floodplain areas. See Design Considerations below for details.

Maintenance
Between 2012-2016 8.7 miles of the IMW study area was treated with 654 PALS (Appendix C; Bennett et al. 2021). Since 2016, maintenance of high LWD density in the original 8.7 miles of restoration was conducted by adding wood and/or posts to structures, adding loose wood to the treatment section, falling, and grip-hoisting whole trees into the treatment sections (Bennett et al. 2021). Maintenance needs are determined after monitoring surveys are conducted and when wood density is determined to be decreasing compared to control sections. We propose to continue maintenance as needed. Maintenance will also be focused on areas that could lead to increased side-channel or floodplain connection. See Design Considerations below for details.

New Treatment Sections
In addition to maintenance, we propose to implement 6 miles of new treatment in sections that are currently control sections in the IMW (i.e., section 3 of Charley, section 2 of North Fork, and the lower mile of section 1 of South Fork[1]). Increasing the size of the existing treatment areas may also increase habitat and fish responses, make the streams more resilient to high flow events, and thereby increase our ability to detect habitat and fish responses (Roni et al. 2010). We will use the same approach to designing low-tech structures as we used in the initial IMW treatments and field design structures in high densities (3-5/100m). In Charley Creek we will build PALS to increase complexity and BDAs to create deep water to connect to side-channels and floodplain. In North Fork Asotin Creek we will build larger PALS and use more whole trees (available due to the recent fire) because the North Fork has the biggest flows and bankfull width. Structures will also be added to newly connected side-channels and floodplain to continue to increase the frequency of pools, channel complexity, and inundation of floodplain. See Design Considerations below for details.

Cost Estimate
A complete cost estimate for the project has been upload to PRISM. Below we provide a summary of the design and construction (Table 3).

[1] The upper 1 mile of South Fork section 1 was treated with PALS in 2016.

Table 3. Estimated construction costs of the proposed berm removal and installation of more large woody debris structures.

Task	Description	Estimated Cost ($)
Design & Field Fit	Identifying confining berms and structure locations	14,400
Excavator equipment & operator	Strategic opening berms of to connect side-channels and/or floodplain	26,400
Construction Labor	Five-person crew working 80 days	220,000
Construction Supervision	Construction Manager working 80 days	48,000
Materials	Trees and brush for PALS, BDAs, and key pieces (match from Private, WDFW & USFS lands)	30,000
TOTAL		$338,800

Design Considerations and Analyses

There are three design elements in the proposed project: identifying and opening berms, continuing maintenance of existing IMW treatments, and installing 6 more miles of low-tech process-based restoration. Below we provide the specific design criteria and objectives for each of the elements of the project. We also provide a proof of concept of the berm opening.

Identification and opening of berms

High banks and historic berms are preventing timely connection of side-channels and floodplain despite some progress since restoration began. Berms are composed of mostly large gravels and cobbles and are resistant to erosion because of existing riparian vegetation locking the channel in place (Figure 1).

Figure 1. Example of berms confining a section of the North Fork Asotin Creek. The post-assisted log structure on river right was installed in 2014 to widen the channel, build bars, and connect to historic side-channels on river left behind the berm. The PALS did widen the channel 3-4' and develop bars but did not open the berm.

Proof on Concept

In 2021-2022, we identified one confining berm through field observations in each study stream. Each berm was cutting off significant side-channel and floodplain habitat (Figure 2-4). We opened the berms at the head of historic side-channels by digging by hand and installed structures in the mainstem to back water up to the openings in the berms (Figure 4). However, it took several days with a crew of 3-5 to open the berms by hand digging and we could not fully open the berms (i.e., dig down the elevation of the mouth of the side-channel to the same elevation of the main channel) due to tree roots and large substrate (Figure 5). These three side-channel connections led to approximately 3.0 acres of floodplain and 2,000' of side-channels (Figure 2-4).

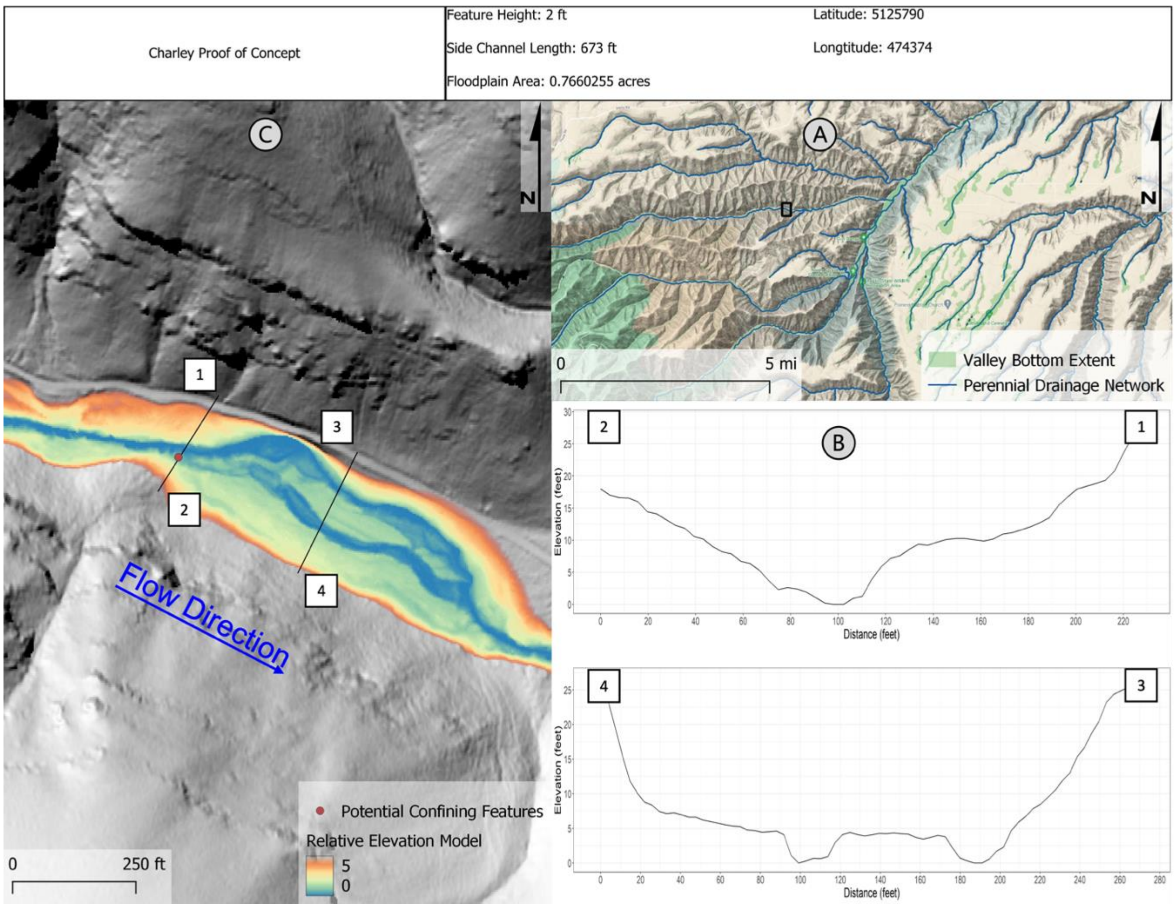

Figure 2. Charley Creek proof of concept where we connected a historic side-channel by hand digging a berm down and installing a beaver dam analog to force water into the side-channel. Panels A identifies the location of site (black box), Panel B provides a cross-section at the confining feature (from points 1-2) and a cross-section across the recently connected side-channel and floodplain (from points 3-4).

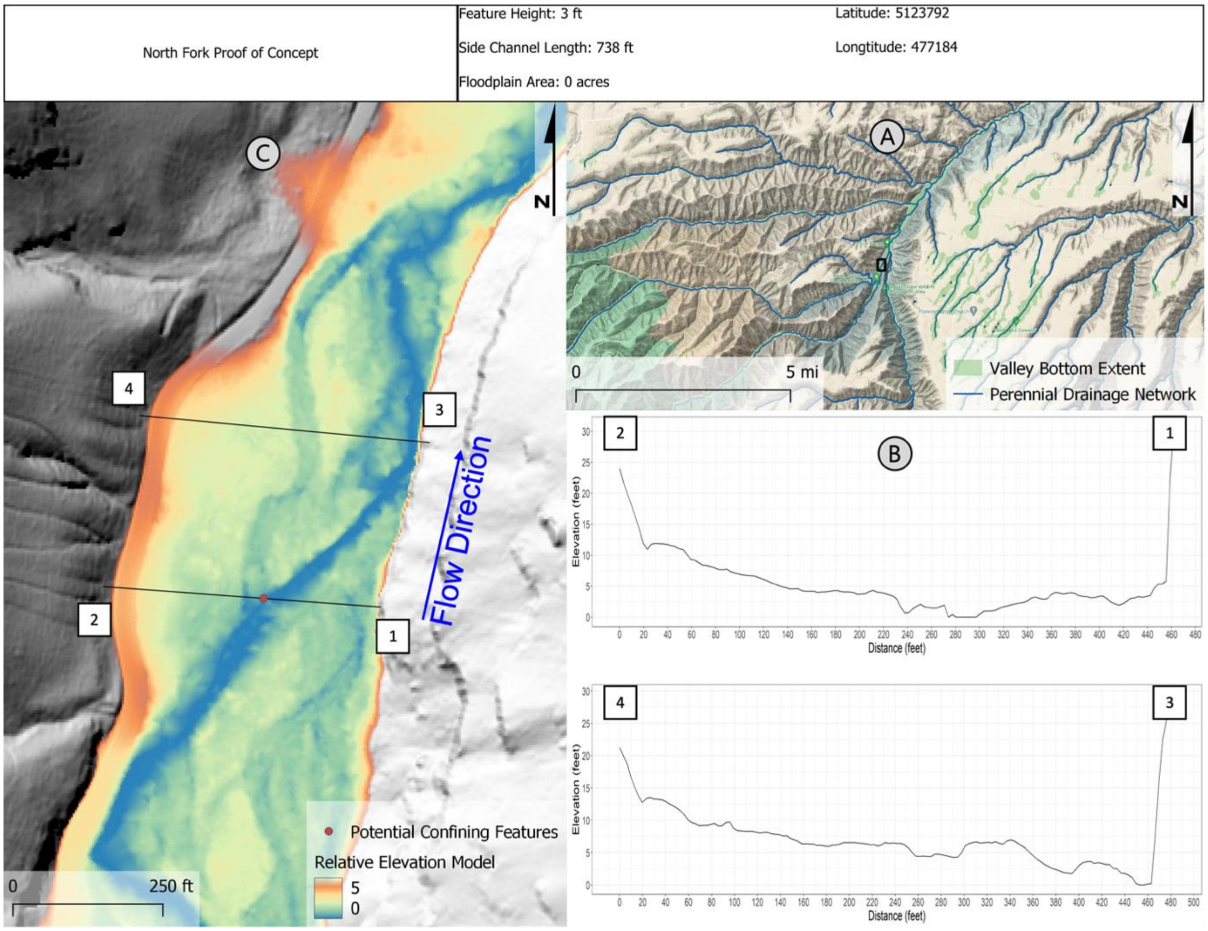

Figure 3. North Fork Asotin Creek proof of concept where we connected a historic side-channel by hand digging a berm down and installing a beaver dam analog to force water into the side-channel. Panels A identifies the location of site (black box), Panel B provides a cross-section at the confining feature (from points 1-2) and a cross-section across the recently connected side-channel and floodplain (from points 3-4).

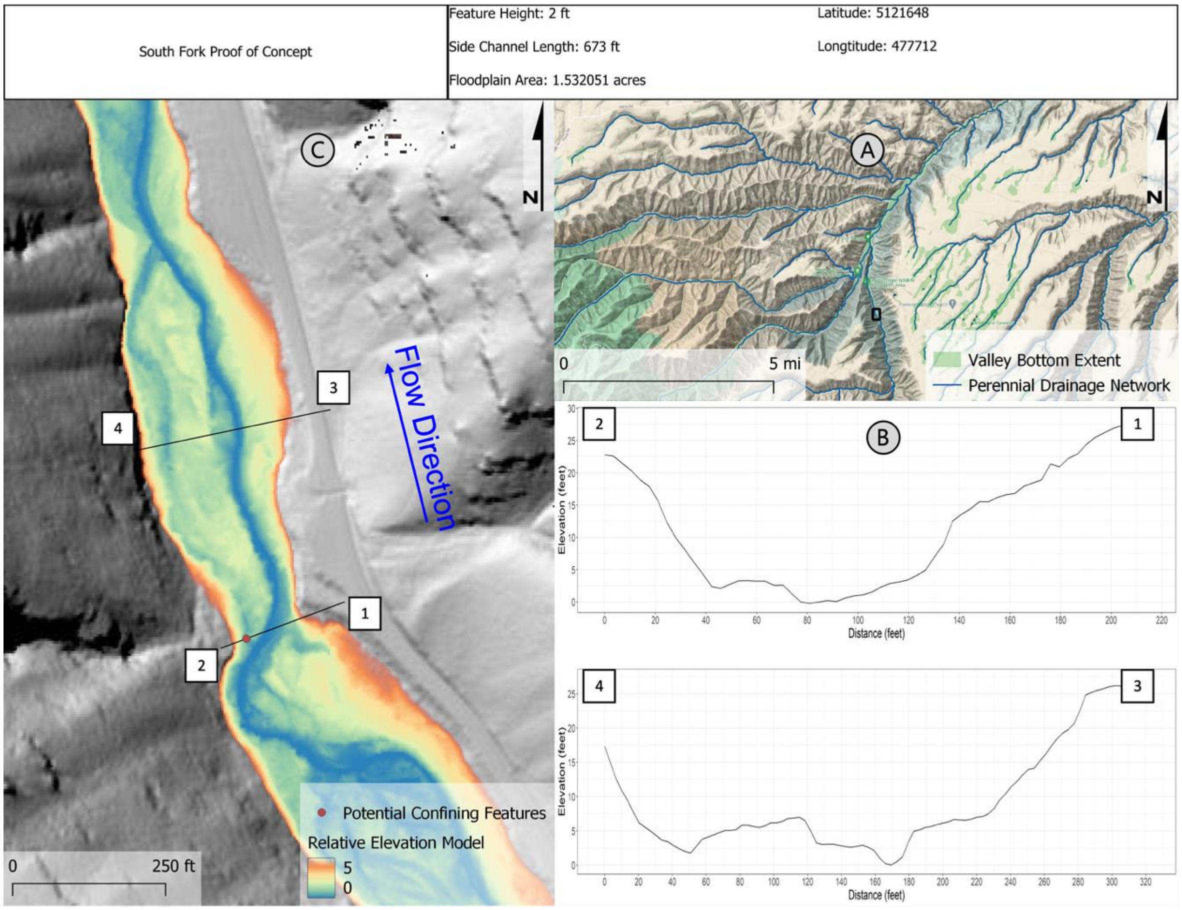

Figure 4. South Fork Asotin Creek proof of concept where we connected a historic side-channel by hand digging a berm down and installing a beaver dam analog to force water into the side-channel. Panels A identifies the location of site (black box), Panel B provides a cross-section at the confining feature (from points 1-2) and a cross-section across the recently connected side-channel and floodplain (from points 3-4).

Figure 5. Digging open a berm at the head of a river left abandoned side-channel on North Fork Asotin Creek. Top left October 2021. Top Right and middle photos April 2022. Bottom photo September 2022. Red arrows reference the same alder tree. Post-assisted log-structure downstream of side-channel was built larger in September 2022 to backwater into side-channel.

Scaling-up Side-channel and Floodplain Connection – Phase 1

We propose to dramatically increase the connection of side-channels and floodplains by identifying berms that are cutting off lateral connection between the main channel and historic side-channels and/or floodplains and opening key portions of the berms with a small excavator. This will be more efficient and allow more complete reconnection than by hand digging.

We used a relative elevation model derived from 1 m LiDAR acquired in 2012 to identify strategic locations in berms (> 2′ and < 5′ tall) that if excavated could maximize connection of side-channel or floodplain habitat (Appendix F). We identified 96 berms across the three study streams that could be targeted for opening (Appendix G & H). Some of the berms will connect side-channels, floodplains, or both, depending on the topography. We ranked each berm based on the access to the site, and the amount of potential side-channel and floodplain could be activated. Maximum rank in each category was 3 and total rank was 9. We will field assess berms within each stream starting with the highest ranked.

We will build PALS or BDAs in the main channel to help promote connection by aggrading sediment and back-watering into newly connected floodplain areas (see phase 2). We will also build PALS and BDAs in the reconnected areas as needed based on maximizing the area of side-channels and floodplains and providing pools and off-channel habitat for rearing and flow refugia for steelhead, and other species (i.e., lamprey, bull trout, Chinook). We estimate that approximately 2.5-3.0 miles of side-channels could be reconnected and 10-15 acres of floodplain (Appendix H).

Berm Opening Objectives

- Field validate ranking of identified berms and select 20-30 confining berms for potential removal
- Use a mini-excavator or other suitable machine to open holes in 20-30 key confining berms (not complete removal)
- Reconnect 10-15acres of new floodplain and 2.0-3.0 miles of side-channels

New Treatment Sections – Phase 2

New treatments will be applied using the lessons learned to date in the IMW (Hillman 2019, PNAMP 2019, Bilby et al. 2023 DRAFT). We will build PALS that are larger and constrict more of the channel to force greater hydraulic and geomorphic change (i.e., 80-90%). We will fall large diameter trees (>20-30″ diameter; "key pieces) and use grip hoists to pull in trees and root wads to build large stable jams that can force floodplain connection, and buffer high flows. Lastly, we will use BDAs in Charley, South Fork Asotin Creek, and connected side-channels in all three study streams to promote overbank flow, deep water pools, and floodplain connection. The mainstem of the North Fork is not suitable for BDAs.

New Treatments - Design

The structure locations will be field fit once high priority berms have been identified and opened (Phase 1). Structures will be designed using the criteria described in (Wheaton et al. 2019, Appendix I). PALS and whole trees will be the dominant structure types. We will use all types of PALS (bank-attached, mid channel, and channel spanning) to maximize channel complexity. Whole trees will be used to build large log jams that will be secured by key pieces (i.e., large diameter channel spanning trees, Figure 6). We propose to install new low-tech process-based structures and whole trees in section 3 of Charley Creek, section 2 of North Fork, and section 1 of South Fork (Appendix C, Table 4). This will increase the total length of treated sections in the IMW from 8.7 miles to almost 15 miles (i.e., 66% of stream length) with a total of 7.5 miles maintained as control sections (33% of the IMW study area, Appendix C). Structure density will range between 30-90 structures depending on stream size. The majority of the LWD will be sourced onsite from alder and burned conifer species in the floodplain and on the lower hillslopes (Appendix D).

Figure 6. Hand built log jam on the North Fork composed of large diameter key piece felled into the stream with addition smaller trees and natural wood racking.

Table 4. Location and number of low-tech process-based structures (post-assisted log structures & beaver dam analogs) and whole trees to be installed. See Appendix C for locations.

Stream	Section	River Mile	PALS	Trees	BDAs	Structure Spacing
Charley	3	5.0-7.5	75-100	50-75	20-30	70-90/mi
North Fork	2	2.5-5.0	75-100	75-100	0	30-50/mi
South Fork	1	0.0-1.3	25-50	50-75	10-20	60-80/mi
TOTAL	-	6.3	175-250	175-250	30-50	30-90/mi

New Restoration Treatment Objectives

- Increase channel complexity, sinuosity,
- Maintain side-channel and floodplain reconnection at low and high flows (once berms have been opened)
- Create or enhance (i.e., make existing pools larger and/or deeper) 100-125 new pools

Maintenance - Ongoing

We would continue to maintain existing and new restoration treatments as we have previously (2016-2022), targeting locations where LWD frequency has decreased due to wood movement to promote increased habitat complexity, and connection of side-channels, or floodplain.

Maintenance Objectives

- Maintain or increase LWD frequency in treatment sections compared to control sections

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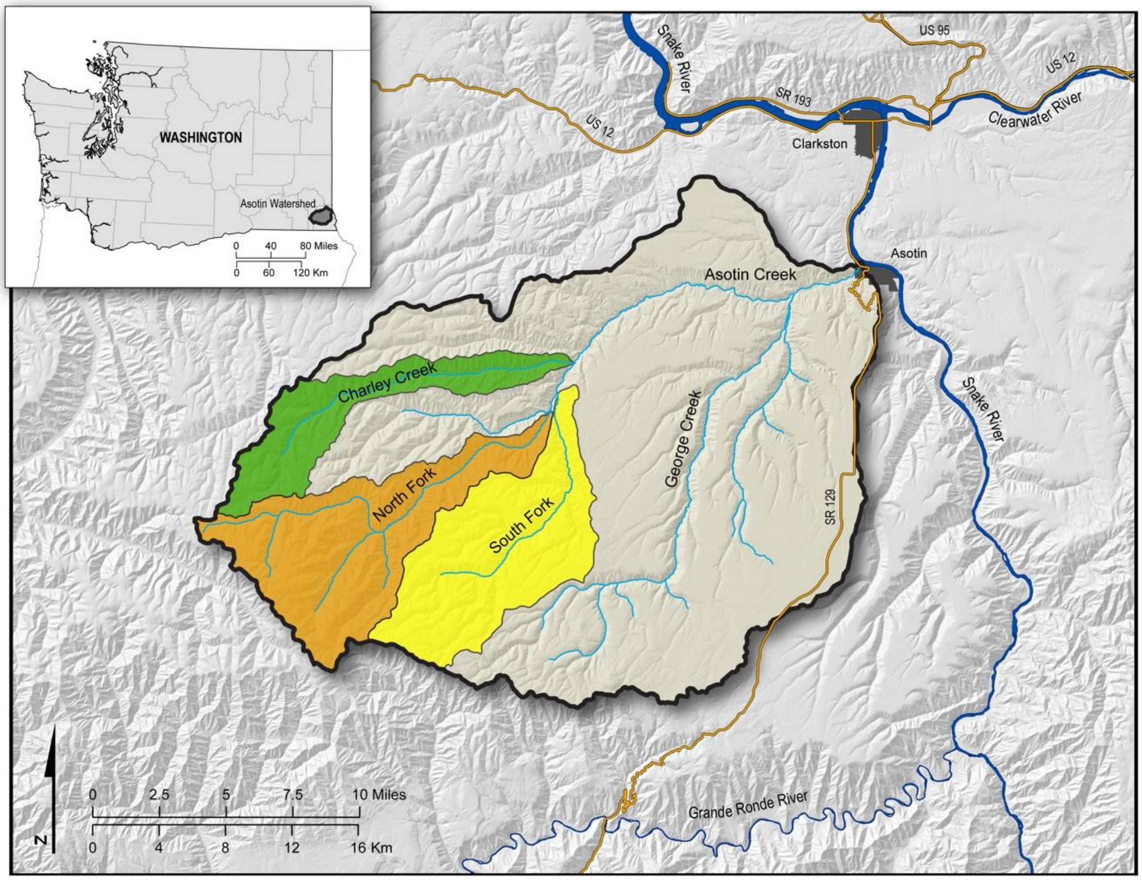
Appendix A – Location of Asotin Creek and the three study streams in the Asotin Creek Intensively Monitored Watershed.



Appendix B - Principles of Riverscape Health and Restoration

Riverscape Principles

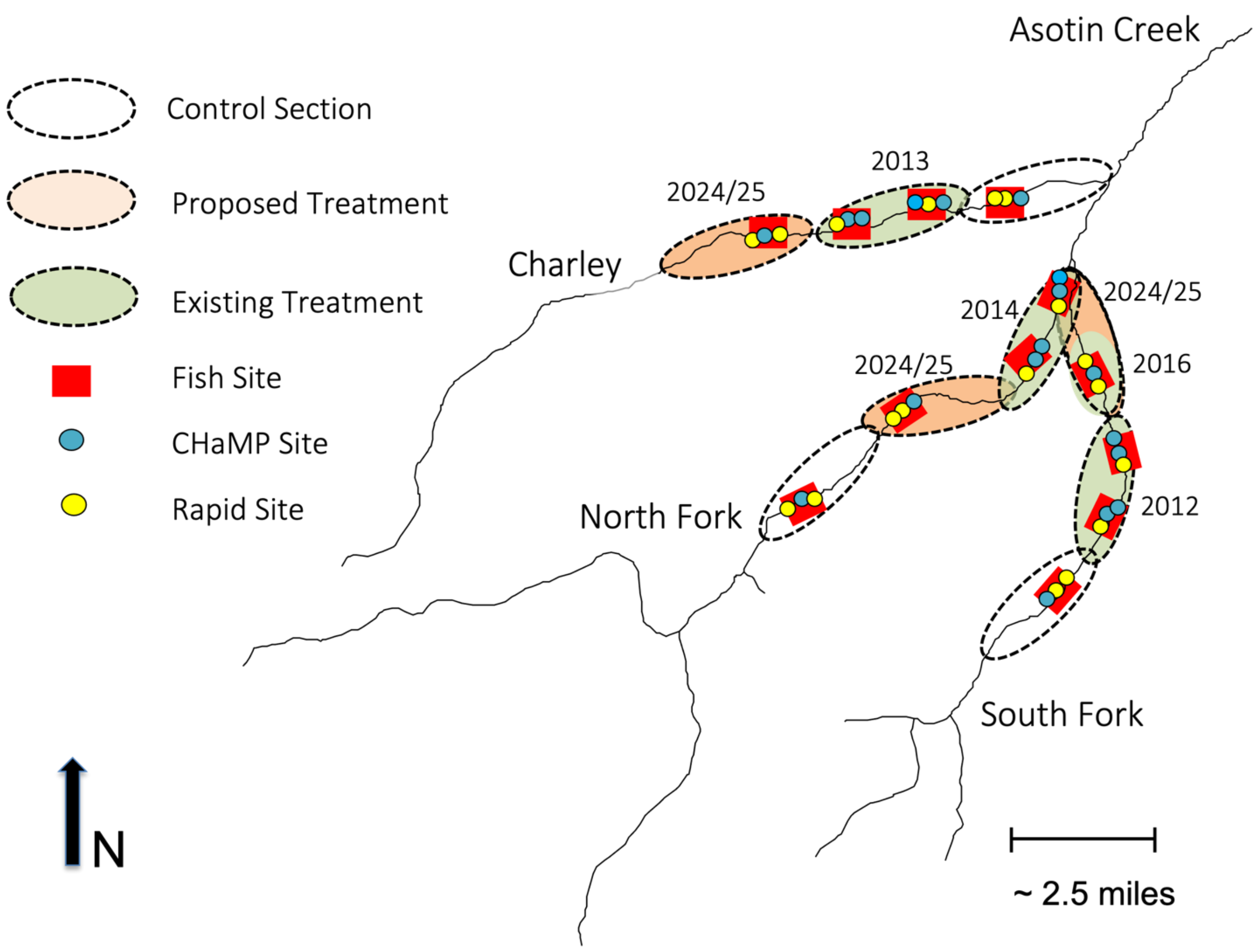
1. **Streams need space**. Healthy streams are dynamic, regularly shifting position within their valley bottom, re-working and interacting with their floodplain. Allowing streams to adjust within their valley bottom is essential for maintaining functioning riverscapes.
2. **Structure forces complexity and builds resilience.** Structure, such as beaver dams and large woody debris, force changes in flow patterns that produce physically diverse habitats. Physically diverse habitats are more resilient to disturbances than simplified, homogeneous habitats.
3. **The importance of structure varies.** The relative importance and abundance of structure varies based on reach type, valley setting, flow regime and watershed context. Identifying the reach type(s) within your project area helps develop realistic expectations about what that stream should or could look (form) and behave (process) like.
4. **Inefficient conveyance of water is often healthy.** Hydrologic inefficiency is the hallmark of a healthy system. Diverse residence times for water can attenuate damaging floods, recharge groundwater, and slowly release water, elevating baseflow and producing critical ecosystem services.

Restoration Principles

5. **It's okay to be messy.** When structure is added back to streams, it is meant to mimic and promote the processes of wood accumulation and beaver dam activity. Structures are fed to the system like a meal and should resemble natural structures (log jams, beaver dams, fallen trees) in naturally 'messy' systems. Structures do not have to be perfectly built to yield desirable outcomes. Focus less on the form and more on the processes the structures will promote.
6. **There is strength in numbers.** Many smaller structures working in concert with each other can achieve much more than a few isolated, over-built, highly-secured structures. Large numbers of structures provides redundancy and reduces the importance of any one structure.
7. **Use natural building materials.** Natural materials should be used because structures are simply intended to initiate process recovery and go away over time. Locally sourced materials are preferable because they simplify logistics and keep costs down.
8. **Let the system do the work.** Giving the riverscape and/or beaver the tools (structure) to promote natural processes to heal itself with stream power and ecosystem engineering, as opposed to diesel power, promotes efficiency that allows restoration to scale to the scope of degradation.
9. **Defer decision making to the system.** This downplays the significance of uncertainty due to limited knowledge. For example, choosing a floodplain elevation to grade based on limited hydrology information can be a complex and uncertain endeavor, but deferring to the hydrology of that system to build its own floodplain grade reduces the importance of uncertainty.
10. **Self-sustaining systems are the solution.** Low-tech restoration actions in and of themselves are not the solution. Rather they are just intended to initiate processes and nudge the system towards the goal of building a resilient, self-sustaining riverscape.

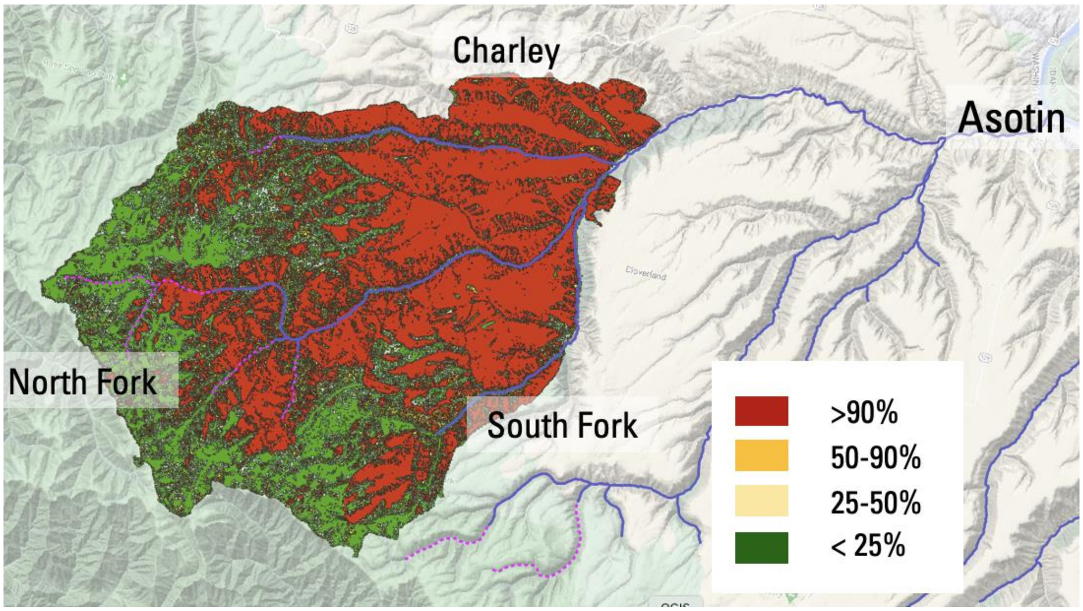
Appendix C – Existing and proposed restoration sections in the Asotin Creek Intensively Monitored Watershed Study Area.

Maintenance and enhancement of existing restoration sections (green sections) will be implemented as needed in 2023-2025. One new section in Charley Creek and North Fork Asotin Creek will be restored with 200-300 post-assisted log structures, 150-200 trees, and 20-30 BDAs 5 miles. Beaver dam analogs will only be used in Charley Creek and South Fork Creek as required to connect side-channels and floodplain.



Appendix D – 2021 Lick Creek Rapid Assessment of Vegetation Condition (RAVG; Zapkora 2021).

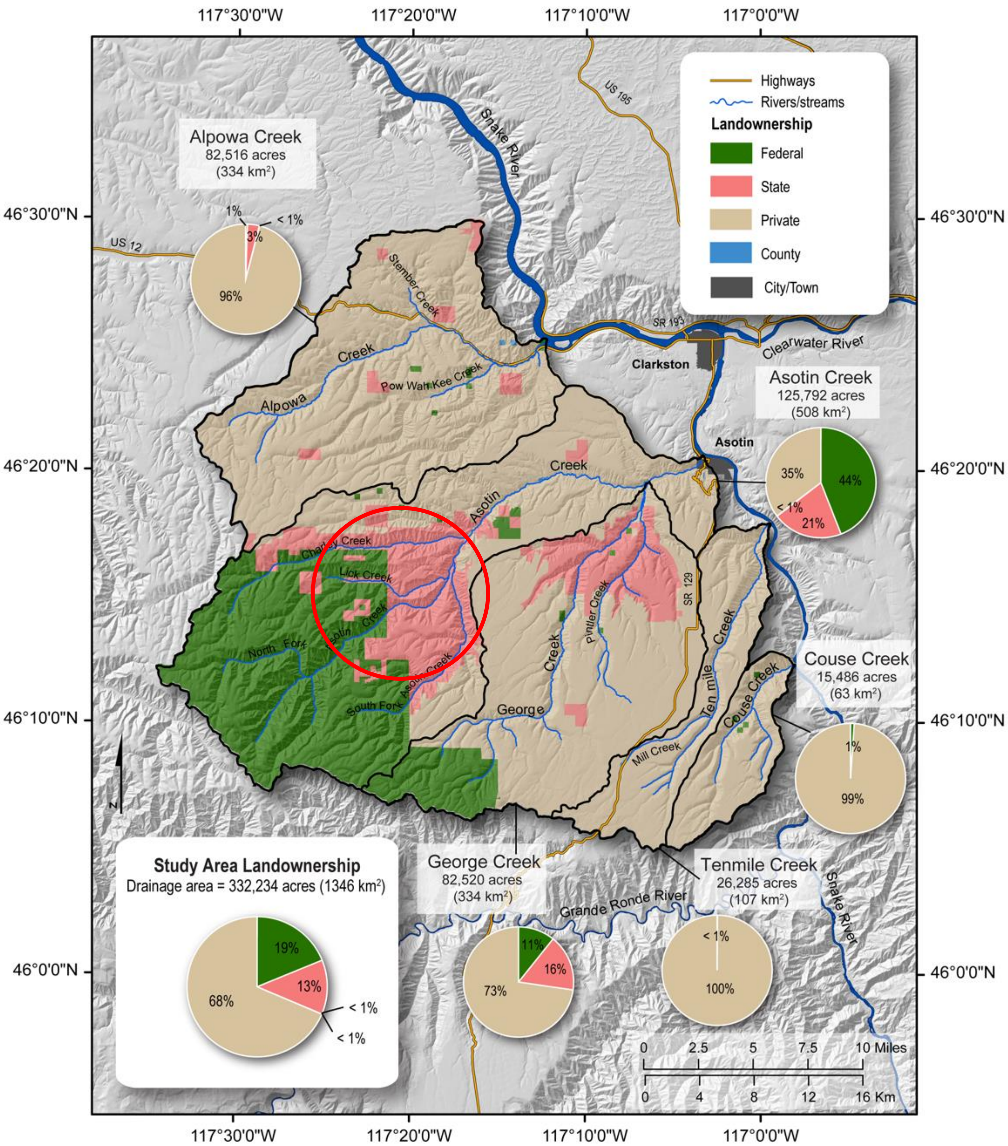
High intensity vegetation burns in lower reaches of Charley, North Fork, and South Fork were mostly on steep hillsides composed of mostly grasses and shrubs.



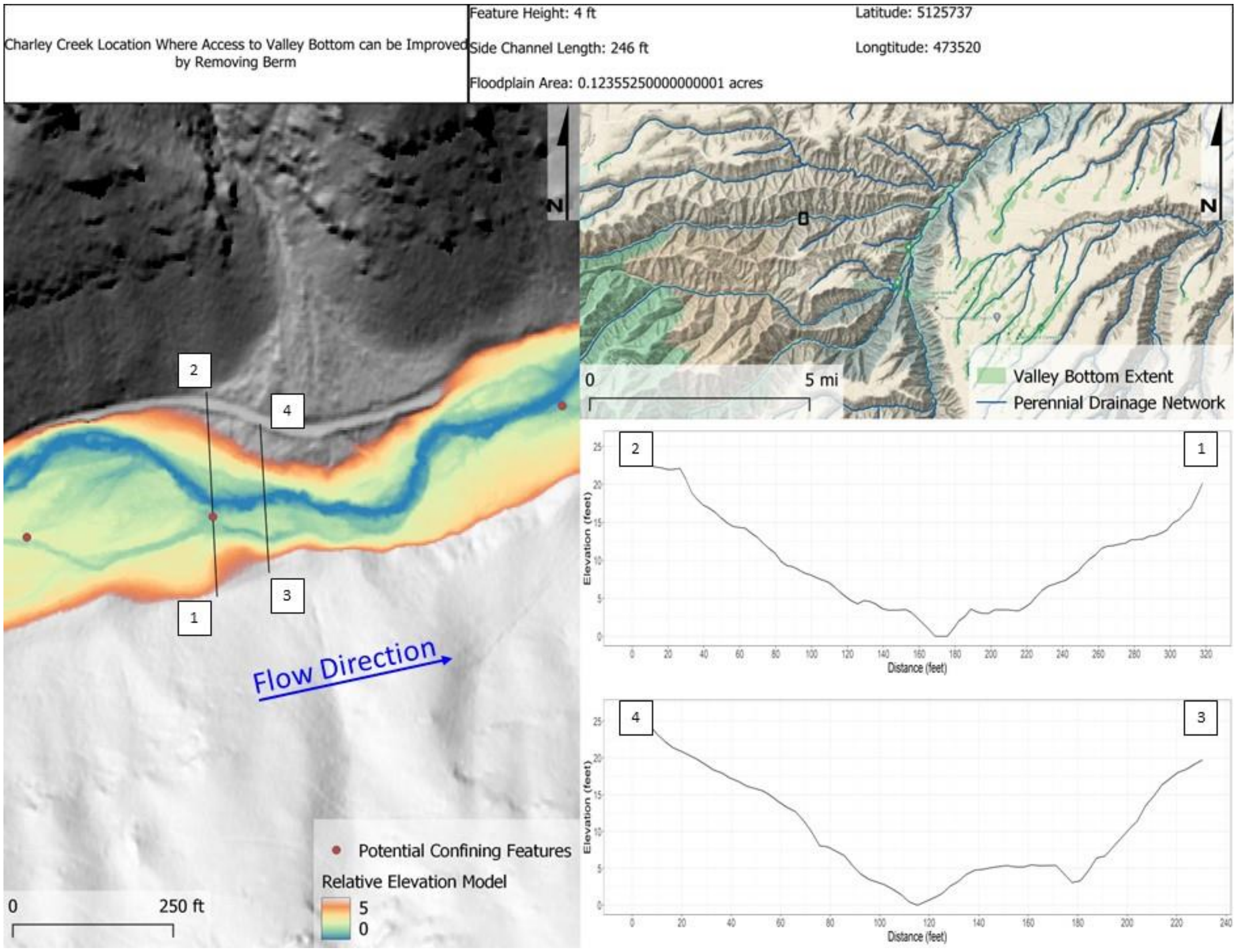
Example of hillside and riparian vegetation burn along lower Charley Creek (left) and valley and hillside vegetation on upper North Fork Creek (right).

Appendix E – Landownership in Asotin Creek, and surrounding watersheds.

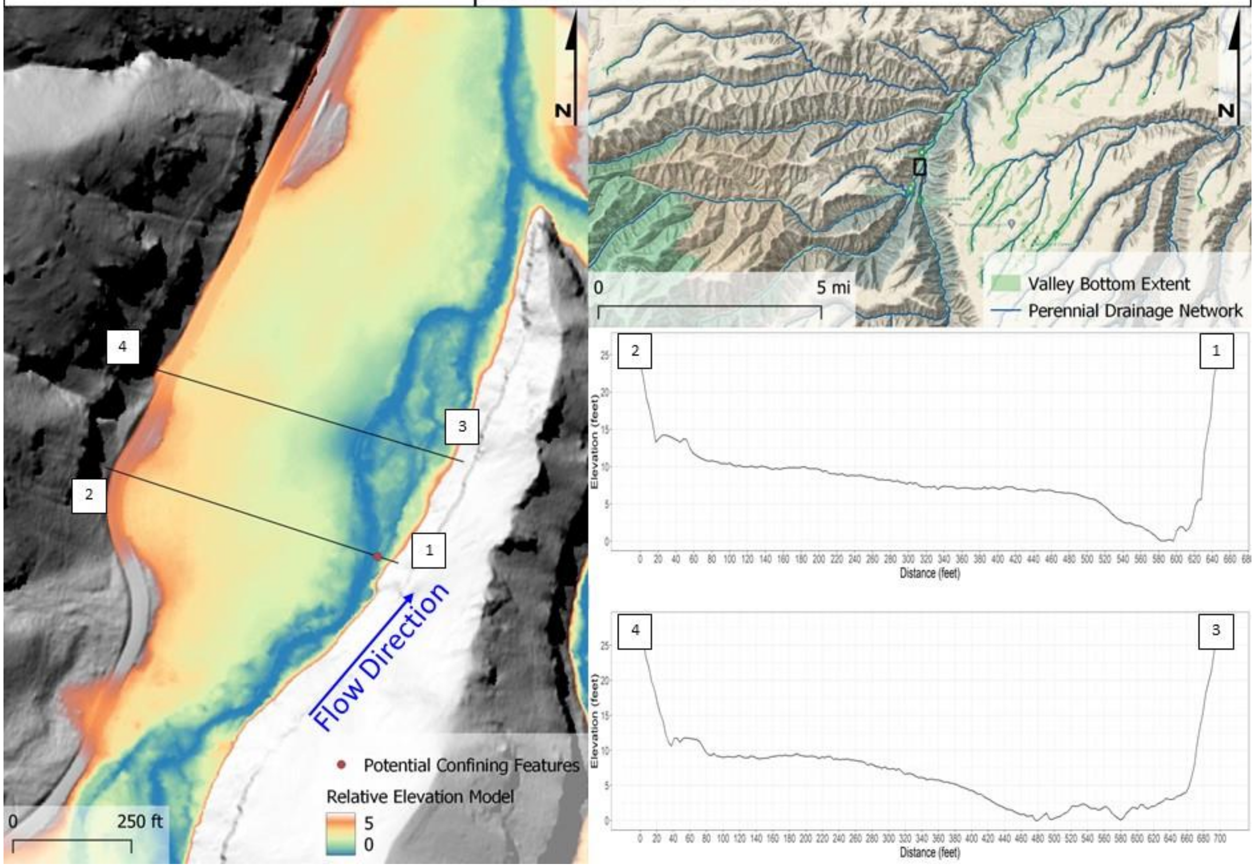
Red circle denotes the Asotin Creek IMW on state (Asotin Wildlife Management Area) and USFS lands.



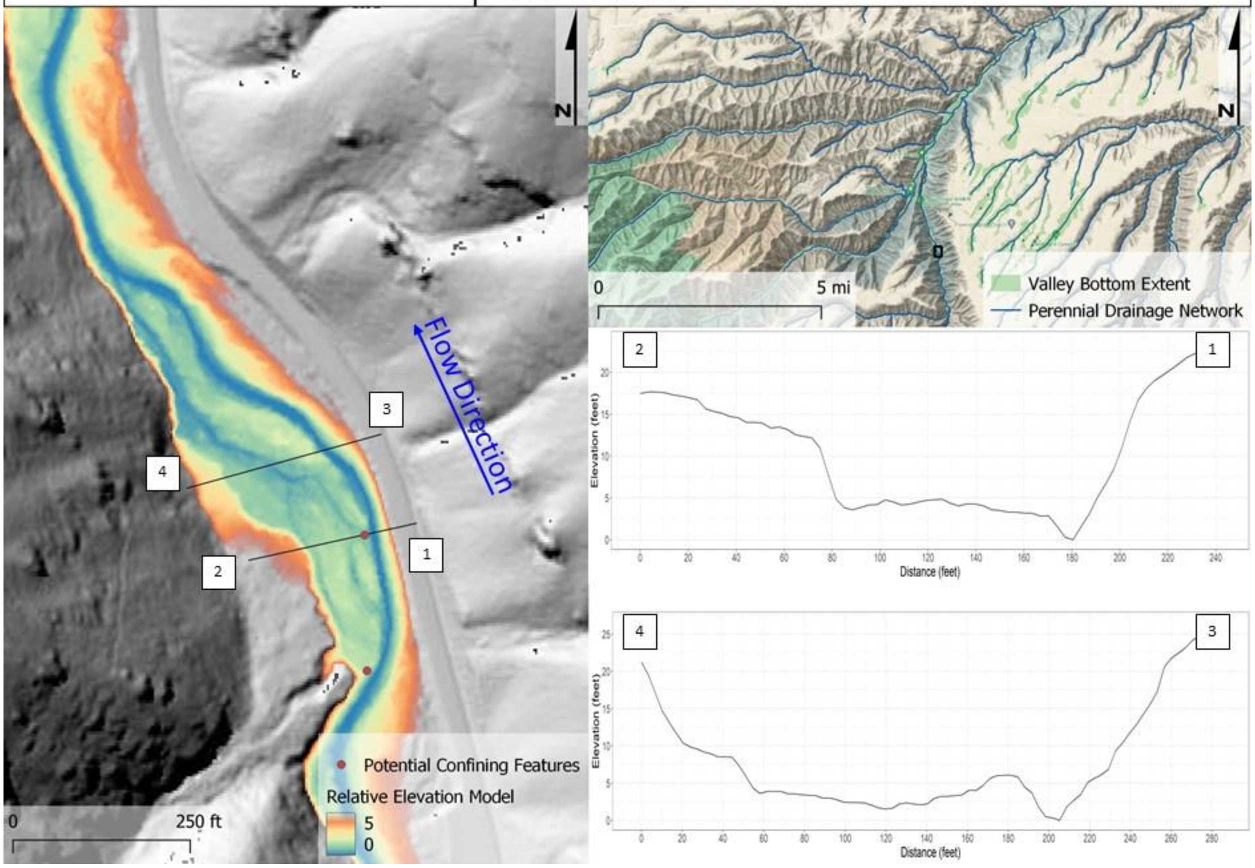
Appendix F. Examples of berms that could be opened on Charley, North Fork, and South Fork Asotin Creeks to increase side-channel and floodplain habitat.



North Fork Asotin Location Where Access to Valley Bottom can be Improved by Removing Berm	Feature Height: 3 ft Side Channel Length: 492 ft Floodplain Area: 1.4084984999999999 acres	Latitude: 5124098 Longtitude: 477393



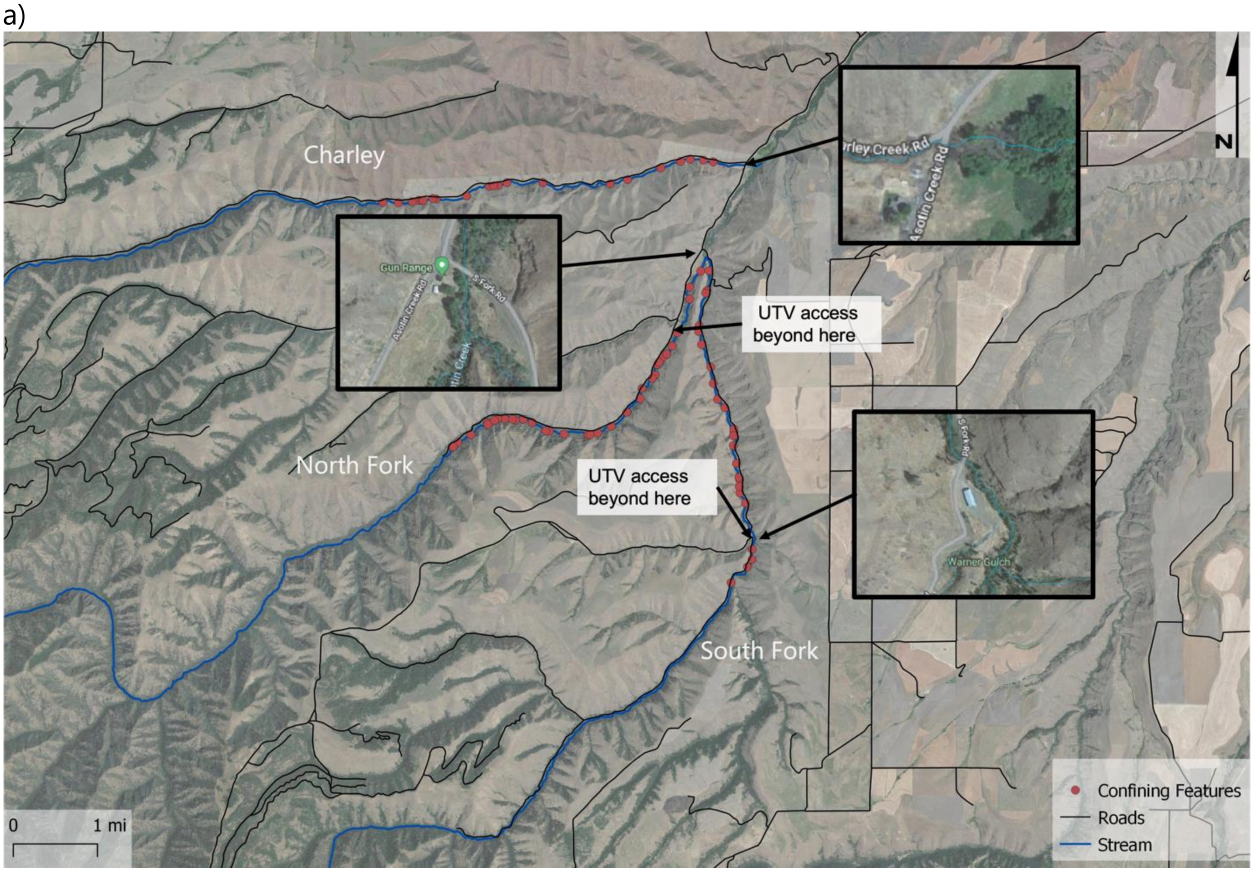
South Fork Asotin Location Where Access to Valley Bottom can be Improved by Removing Berm	Feature Height: 3 ft Side Channel Length: 525 ft Floodplain Area: 0.5189205 acres	Latitude: 5121077 Longtitude: 478028



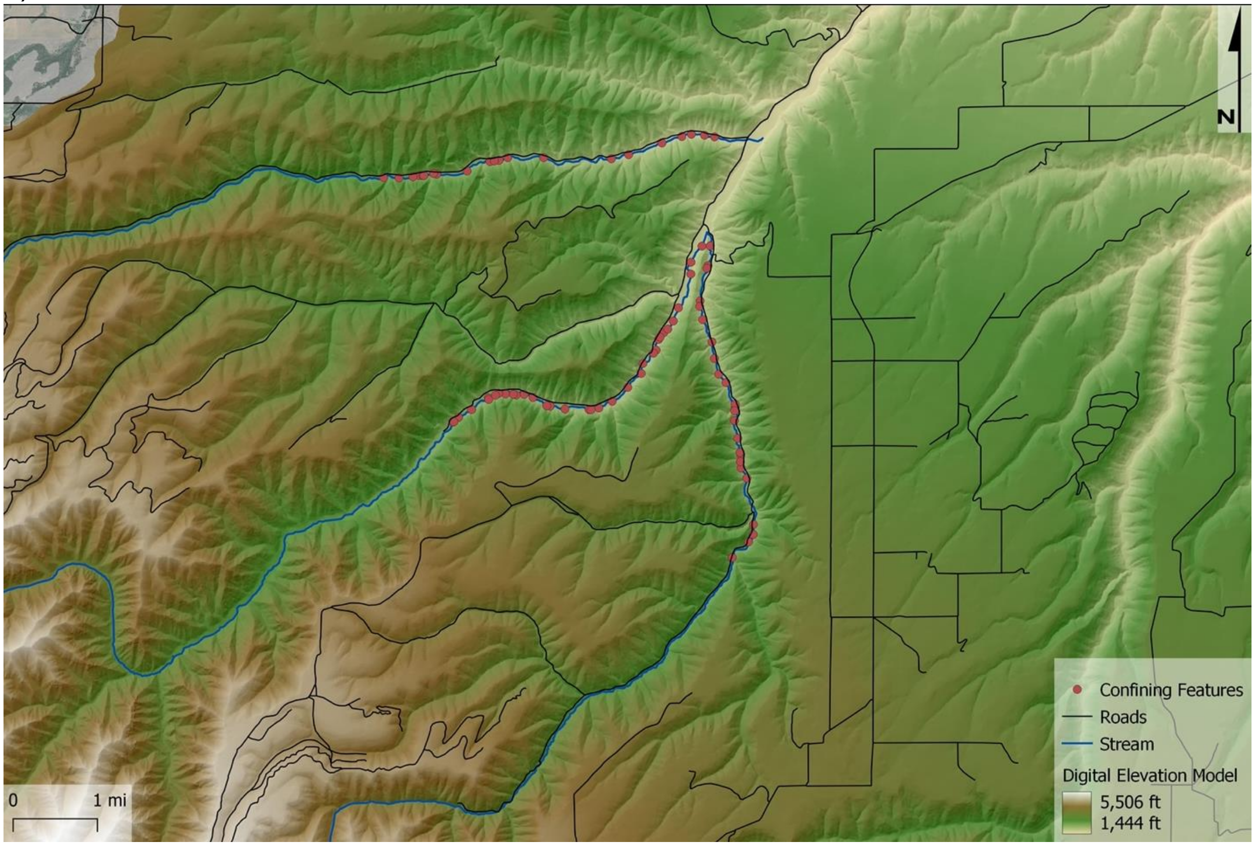
Appendix G – Locations of roads, infrastructure, and potential confining berms within the Asotin IMW study area.

a) Base map google imagery with infrastructure identified. Inset maps identify private house at the mouth of Charley Creek, and high clearance bridges and storage facilities at the mouth of North Fork and approximately 5 miles upstream on South Fork. b) Base map the digital elevation model showing topographic relief. All roads are county gravel roads except unimproved road up Charley Creek, and two UTV trails with only non-motorized public access on North Fork and South Fork as noted on map a).

a)



b)



N
Confining Features
Roads
Stream
Digital Elevation Model
5,506 ft
1,444 ft
0
1 mi

Appendix H. Location of identified confining berms in a) Charley, b) North Fork, and c) South Fork Asotin Creek, including length of potential side-channel and area of floodplain connection.

Confining berms were ranked based on the access to the site, and amount of potential side-channel and floodplain could be activated. Maximum rank in each category was 3 and total rank was 9. Within each stream berm locations ranked from highest to lowest priority for field inspection and potential berm opening.

a)

StreamName	Berm Height (ft)	Side-channel Length (ft)	Floodplain Area (ac)	Access Rank	Side-Channel Rank	Flood Rank	Total Rank	Lat
Charley	2.9	509	1.2	3	2	3	8	5126070
Charley	2.5	673	0.8	2	3	2	7	5125790
Charley	0.7	377	0.3	3	2	1	6	5125535
Charley	4.9	656	0.5	1	3	1	5	5125715
Charley	2.5	164	0.3	3	1	1	5	5126219
Charley	4.3	394	0.1	1	2	1	4	5125676
Charley	3.3	0	0.0	2	1	1	4	5125761
Charley	2.6	0	0.0	2	1	1	4	5125711
Charley	1.0	164	0.2	2	1	1	4	5126187
Charley	3.3	197	0.2	2	1	1	4	5125789
Charley	3.9	246	0.3	2	1	1	4	5125410
Charley	1.5	82	0.1	1	1	1	3	5125487
Charley	4.9	98	0.1	1	1	1	3	5125403
Charley	2.4	115	0.1	1	1	1	3	5125448
Charley	6.6	164	0.0	1	1	1	3	5125727
Charley	0.3	180	0.2	1	1	1	3	5126194
Charley	4.6	213	0.2	1	1	1	3	5125424
Charley	3.9	230	0.3	1	1	1	3	5125448
Charley	4.8	230	0.3	1	1	1	3	5125448
Charley	3.6	246	0.1	1	1	1	3	5125737
Charley	3.5	246	0.2	1	1	1	3	5125767
Charley	3.7	262	0.4	1	1	1	3	5125872
TOTAL		**5,446**	**6.0**					

B)

StreamName	Berm Height (ft)	Side-channel Length (ft)	Floodplain Area (ac)	Access Rank	Side-Channel Rank	Flood Rank	Total Rank	Lat	Long
North Fork	5.2	755	1.5	3	3	3	9	5120822	472749
North Fork	3.3	902	1.9	3	3	3	9	5123560	477181
North Fork	3.3	787	1.6	2	3	3	8	5121198	473315
North Fork	3.7	656	1.1	1	3	3	7	5120984	474779
North Fork	0.4	623	1.2	2	2	3	7	5121004	475425
North Fork	2.5	410	0.7	3	2	2	7	5121855	476267
North Fork	3.0	738	0.0	3	3	1	7	5123792	477184
North Fork	4.0	476	1.1	1	2	3	6	5122513	476742
North Fork	2.6	492	1.4	1	2	3	6	5124098	477393
North Fork	3.8	344	0.6	2	2	2	6	5120972	472998
North Fork	4.6	410	0.6	2	2	2	6	5121266	473794
North Fork	3.8	427	0.8	2	2	2	6	5121663	476234
North Fork	4.9	394	0.3	3	2	1	6	5123031	477046
North Fork	2.3	646	0.5	3	2	1	6	5123207	477150
North Fork	3.4	377	0.6	1	2	2	5	5120971	475239
North Fork	4.9	377	0.7	1	2	2	5	5120740	472660
North Fork	0.3	131	0.2	3	1	1	5	5122109	476518
North Fork	3.3	164	0.1	3	1	1	5	5122051	476468
North Fork	2.8	262	0.4	3	1	1	5	5122920	476946
North Fork	5.2	295	0.7	1	1	2	4	5121077	473111
North Fork	3.4	295	0.8	1	1	2	4	5120922	472925
North Fork	0.6	295	0.9	1	1	2	4	5121282	473511
North Fork	3.3	394	0.3	1	2	1	4	5121265	473999
North Fork	3.7	427	0.4	1	2	1	4	5121131	475681
North Fork	2.6	197	0.0	2	1	1	4	5121146	475750
North Fork	3.9	213	0.0	2	1	1	4	5121804	476241
North Fork	1.6	180	0.1	2	1	1	4	5120732	472640
North Fork	3.0	213	0.3	2	1	1	4	5122314	476567
North Fork	0.7	115	0.1	1	1	1	3	5121047	474429
North Fork	2.9	180	0.1	1	1	1	3	5122356	476594
North Fork	3.0	180	0.2	1	1	1	3	5122444	476663
North Fork	2.5	197	0.2	1	1	1	3	5121246	473451
North Fork	4.9	197	0.2	1	1	1	3	5121398	475978
North Fork	3.0	230	0.2	1	1	1	3	5121251	473849
North Fork	2.9	246	0.1	1	1	1	3	5121273	473645
North Fork	3.5	246	0.3	1	1	1	3	5121233	475846
North Fork	1.9	246	0.4	1	1	1	3	5122666	476847
North Fork	1.6	262	0.2	1	1	1	3	5121205	474168
North Fork	2.9	279	0.4	1	1	1	3	5121038	474496
North Fork	3.9	295	0.2	1	1	1	3	5120970	475278
North Fork	4.6	295	0.2	1	1	1	3	5121166	473322
TOTAL		**14,852**	**21.9**						

C)

StreamName	Berm Height (ft)	Side-channel Length (ft)	Floodplain Area (ac)	Access Rank	Side-Channel Rank	Flood Rank	Total Rank	Lat	Long
South Fork	2.3	673	1.5	1	3	3	7	5121648	477712
South Fork	3.6	525	0.1	3	2	1	6	5121488	477854
South Fork	3.7	377	0.7	1	2	2	5	5122945	477349
South Fork	3.6	492	0.7	1	2	2	5	5124104	477551
South Fork	3.1	492	0.9	1	2	2	5	5118586	478372
South Fork	2.8	525	0.5	1	2	2	5	5122267	477584
South Fork	3.0	525	0.5	1	2	2	5	5121077	478028
South Fork	3.3	82	0.0	3	1	1	5	5119283	478279
South Fork	3.3	112	0.0	3	1	1	5	5121047	478030
South Fork	2.3	200	0.1	3	1	1	5	5121996	477639
South Fork	1.6	246	0.0	3	1	1	5	5121552	477811
South Fork	2.6	262	0.3	3	1	1	5	5123051	477359
South Fork	2.3	328	0.1	3	1	1	5	5122605	477455
South Fork	2.6	0	0.1	3	1	1	5	5123685	477512
South Fork	2.0	0	0.1	3	1	1	5	5122071	477630
South Fork	2.9	262	0.6	1	1	2	4	5123448	477438
South Fork	3.3	328	0.7	1	1	2	4	5118779	478374
South Fork	1.7	361	0.4	1	2	1	4	5119858	478140
South Fork	2.0	148	0.2	2	1	1	4	5122693	477407
South Fork	3.1	115	0.1	1	1	1	3	5120951	478018
South Fork	2.0	135	0.0	1	1	1	3	5117960	477954
South Fork	4.6	148	0.1	1	1	1	3	5119978	478128
South Fork	2.2	164	0.2	1	1	1	3	5122494	477470
South Fork	2.7	180	0.0	1	1	1	3	5120110	478136
South Fork	3.6	180	0.2	1	1	1	3	5120423	478077
South Fork	3.4	180	0.2	1	1	1	3	5120763	478015
South Fork	2.6	213	0.1	1	1	1	3	5118165	477980
South Fork	3.3	246	0.3	1	1	1	3	5118445	478284
South Fork	3.9	262	0.0	1	1	1	3	5118028	477960
South Fork	1.5	262	0.3	1	1	1	3	5120153	478121
South Fork	3.7	295	0.4	1	1	1	3	5119724	478234
South Fork	4.9	295	0.5	1	1	1	3	5123725	477510
South Fork	3.3	0	0.0	1	1	1	3	5118312	478123
TOTAL		**8,615**	**10.4**						

Appendix I. Low-tech Process-based Construction Methods and Structure Types.

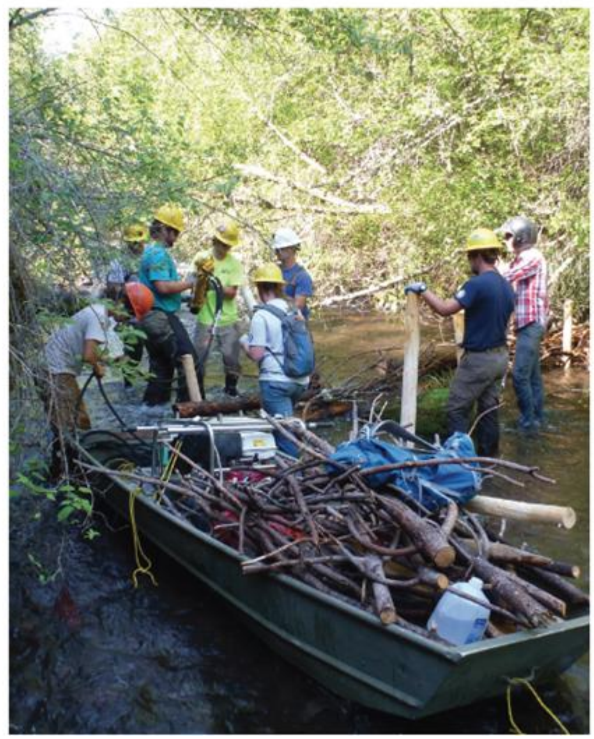
This section outlines general construction methods, the different structure types, how different structure types should be used to promote specific hydraulic and geomorphic responses, and design schematics for Post-Assisted Log Structures (PALS) and Beaver Dam Analogs (BDA). More details can be found in Wheaton et al. 2019.

PALS CONSTRUCTION

POST-ASSISTED LOG STRUCTURES

HOW TO BUILD PALS

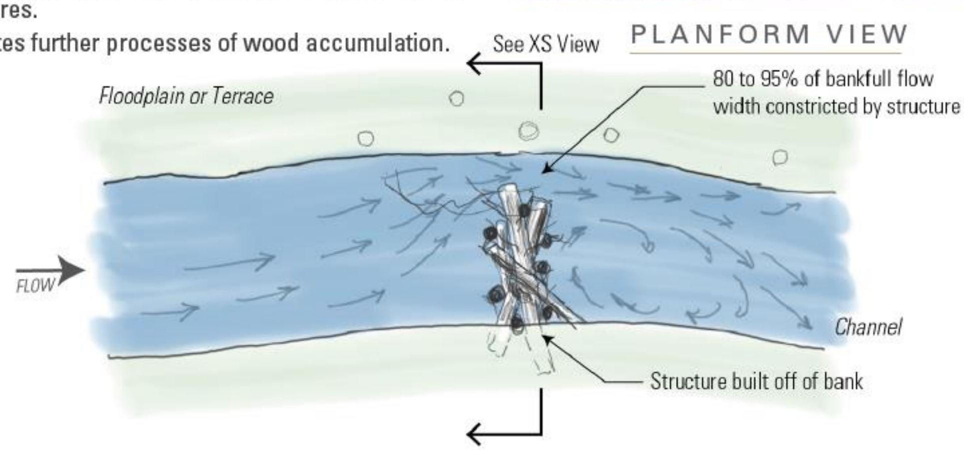
1. Decide location of PALS, configuration (e.g., orientation and type of PALS) as part of the design of a complex of structures (multiple structures working together).
2. Position larger logs on the base of the structure to make the general shape of structure.
3. Limb branches from one side of the logs so that much of the log comes in contact with the bed to increase interaction between the flow and the structure, even at low flows.
4. Pin large pieces in place with posts; drive posts at angles and downstream to help hold wood in place at high flows.
5. Add more logs, and pack and wedge smaller material to fill spaces in the structure.
6. Build up the structure to desired crest elevation, but crest elevation need not be uniform.

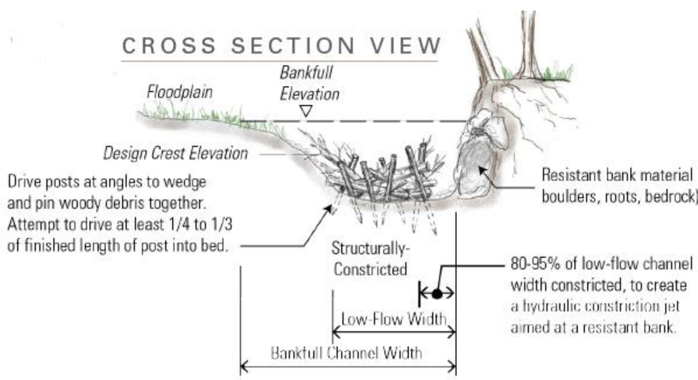


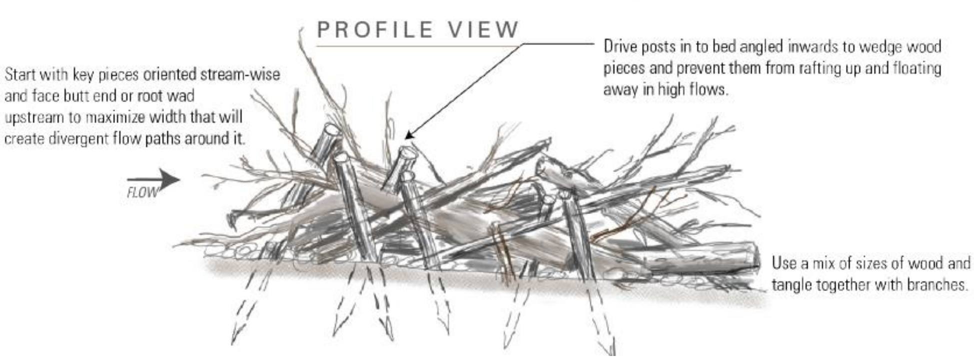
BANK-ATTACHED PALS

VARIATION 1: TO FORCE A CONSTRICTION JET

- Creates convergent jet of flow between bank- or margin-attached structure and a resistant feature (e.g., bedrock bank, roots, wood) on opposite bank.
- Forces more variable hydraulics, which typically create a backwater eddy upstream of the structure, a large eddy in the wake of the structure, and divergent flow paths where the jet weakens.
- Promotes structurally-forced pool, riffle growth at the divergent jet, and eddy bar formation in the eddies. Upstream deposition stabilizes and grows the structures.
- Promotes further processes of wood accumulation.





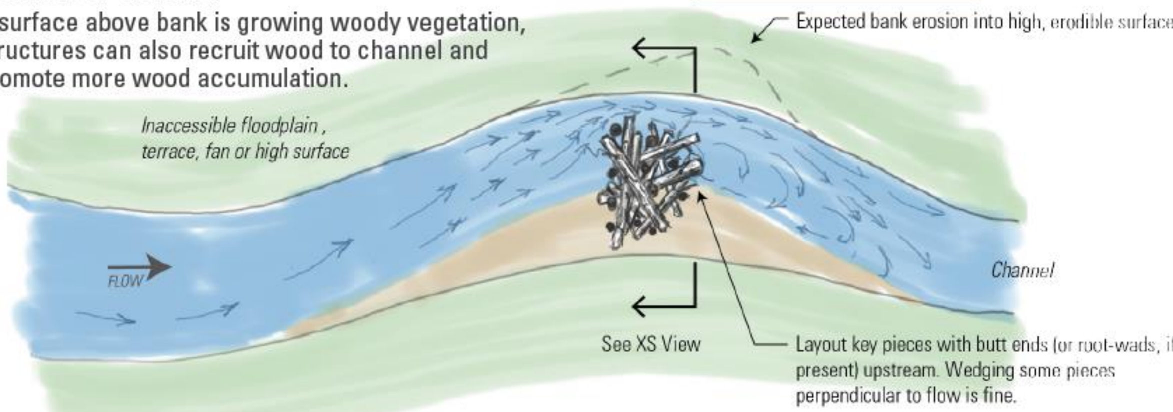


BANK-ATTACHED PALS:

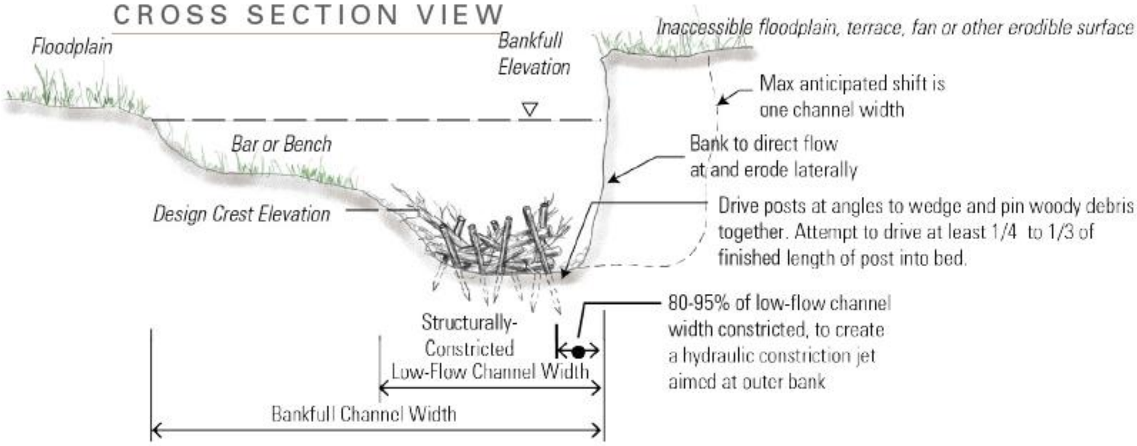
VARIATION 2: BANK BLASTER

- Accelerates lateral widening via bank erosion of an erodible bank opposite of the structure.
- Shunting of flow forces more variable hydraulics, which typically create a backwater eddy upstream of the structure, an eddy downstream of structure, and temporary jet aimed at opposite erodible bank.
- Leads to lateral shift of channel (no more than one channel width typically). Further lateral migration occurs if bar growth continues on inside bend, further natural woody debris accumulates on structure, or subsequent treatment is extended off structure.
- If surface above bank is growing woody vegetation, structures can also recruit wood to channel and promote more wood accumulation.

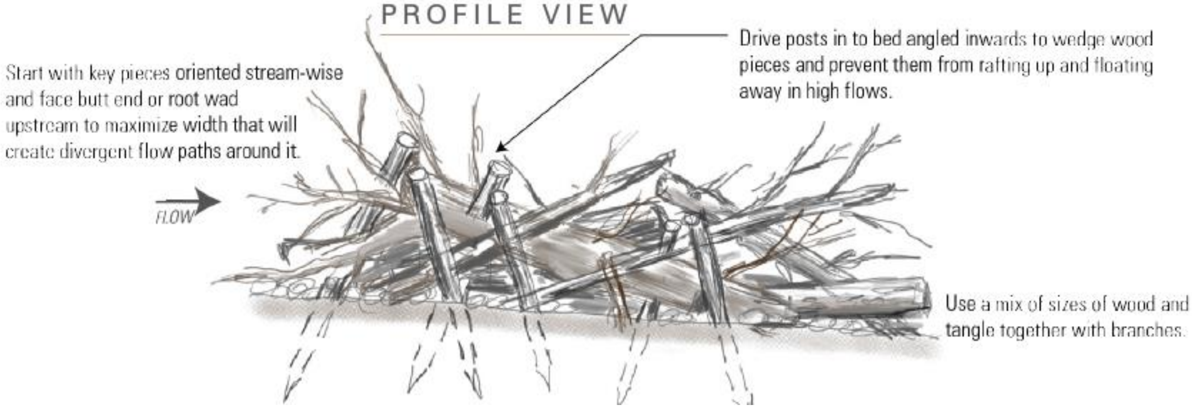
PLANFORM VIEW



CROSS SECTION VIEW



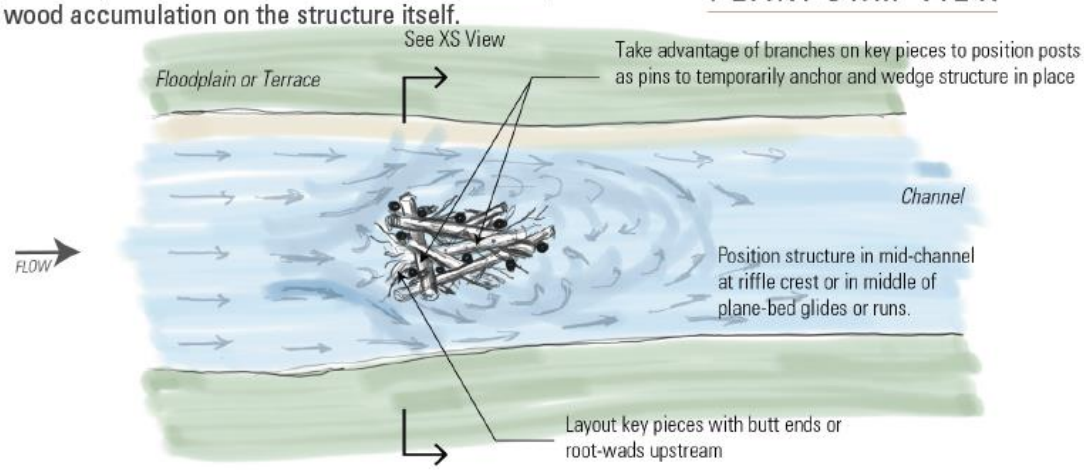
PROFILE VIEW



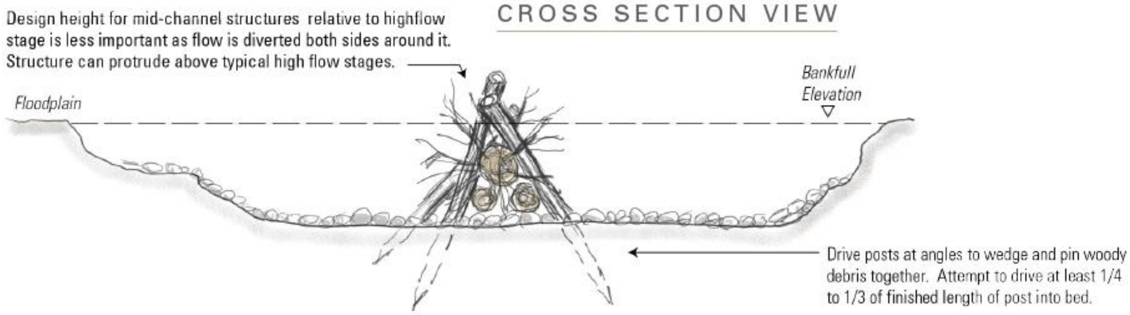
MID-CHANNEL PALS

- Installed mid-channel to split flow around the structure.
- Forces more variable hydraulics, which creates an eddy downstream of structure.
- Can promote mid-channel bar development in place of planebed morphologies, encourage or promote diffluences, convert riffles into mid-channel bars and/or to dissipate flow energy.
- In larger channels, multiple mid-channel PALS can be used in close proximity and are often more effective than a single large structure.
- In all cases, the mid-channel PALS can promote the process of wood accumulation on the structure itself.

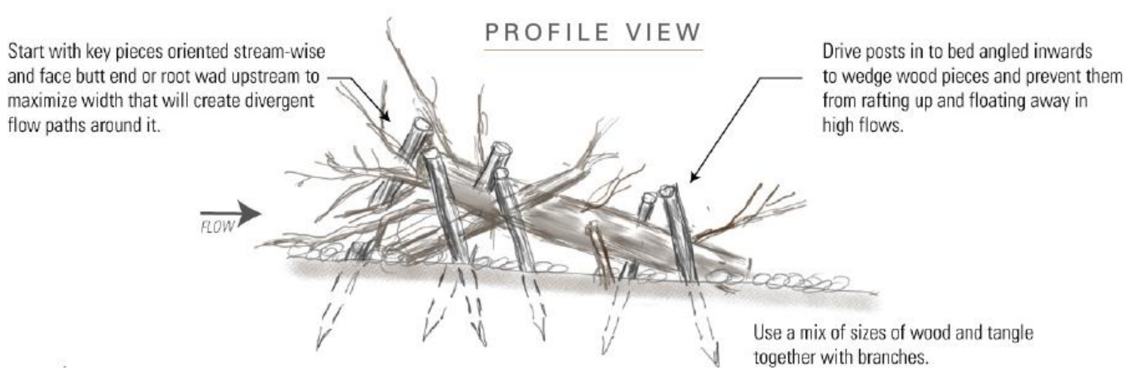
PLANFORM VIEW



CROSS SECTION VIEW



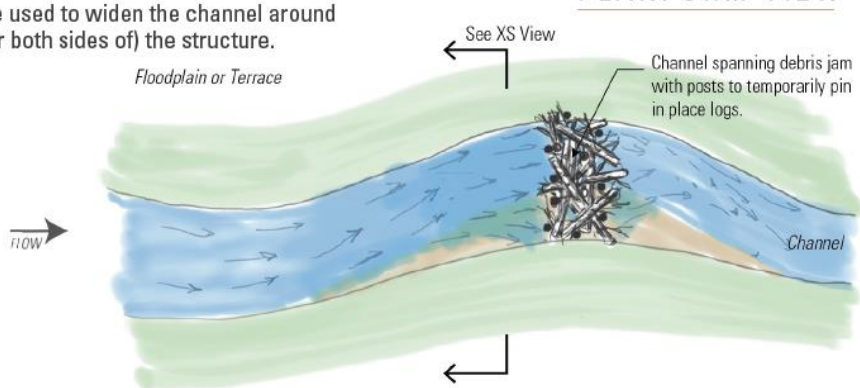
PROFILE VIEW



CHANNEL-SPANNING PALS

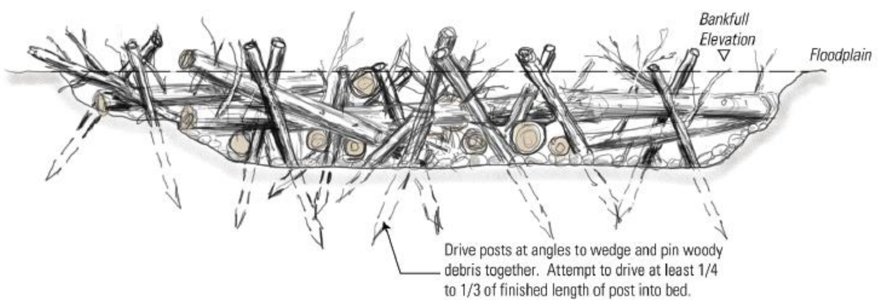
- Bank-attached on both sides, such that even at low-flow there is some hydraulic purchase across most of the channel, acting to back-water flow behind it. Unlike a beaver dam (with a uniform crest elevation), channel-spanning PALS can have a variable crest elevation and rougher finish, and are generally built with much greater porosity.
- Over time, increased water depth and decreased velocity upstream of PALS encourages more wood accumulation, organic accumulation and sediment deposition, all of which can act to stabilize the structure.
- If crest elevations are higher than adjacent floodplain(s), it can increase frequency of floodplain inundation, force new diffluences, and/or promote avulsions.
- Can be used to widen the channel around (one or both sides of) the structure.

PLANFORM VIEW

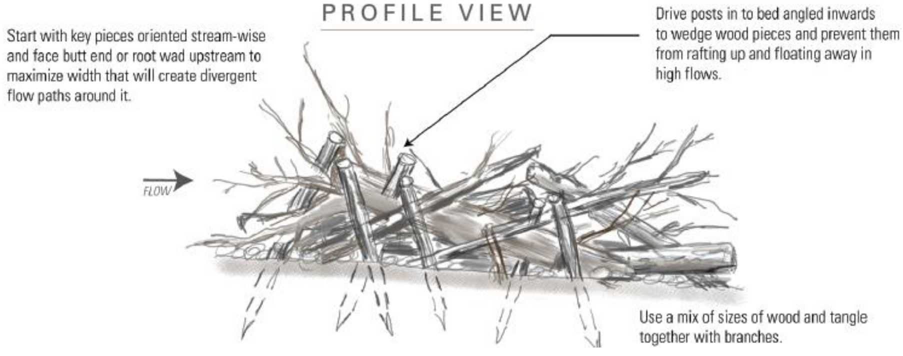


Design height for channel-spanning structures is important. If it is intended Structure can protrude above typical high flow stages.

CROSS SECTION VIEW



PROFILE VIEW



Example of PALS evolution over the course of one year promoting processes of wood accumulation. A and B show a mid-channel PALS becoming a bank-attached PALS, C and D show a bank-attached PALS becoming a debris jam, and E and F show a bank-attached PALS becoming a mid-channel PALS. The geomorphic changes imposed by the presence of the PALS in each example shows clear alterations to the channel bed and hydraulics. From Chapter 4 of Wheaton et al. (2019: http://lowtechpbr.restoration.usu.edu).

HOW TO BUILD BDAs

1. Decide location of BDA dam crest orientation, configuration (e.g., straight or convex downstream), and crest elevation (use landscape flags if necessary). Position yourself with your eye-level at the proposed crest elevation of the dam (make sure it is < 5′ in height). Look upstream to find where the pond will backwater to. Adjust crest elevation as necessary to achieve desired size of pond, inundation extent, and overflow patterns. If concerned about head drop (water surface elevation difference) over BDA, build a secondary BDA downstream with a crest elevation set to backwater into base of this BDA (and lessen head drop or elevation difference between water surface in pond and water surface downstream of BDA).

2. Build up first layer or course by widening base upstream and downstream of crest to flat height of 6 to 12″ above existing water surface, and make sure it holds back water.

   a. If larger key pieces (i.e., larger logs, cobble or small boulders) are locally abundant, these can be used to lay out the crest position across the channel. Optionally, they can be 'keyed' in by excavating a small trench (no need to be deeper than ~1/3 of the height of key piece diameter) and place key pieces in and pack with excavated material.

   b. Lay out first layer of larger fill material, being careful not to go to higher than 6″ to 12″ above existing water surface. The first layer should be just high enough to backwater a flat water surface behind it.

   c. Using mud, bed material & turf (typically sourced from backwater area of pond) as fine fill material to plug up leaks, combine with sticks and branches of various sizes to build a wide base. Make sure base is wide enough to accommodate anticipated dam height (most dams will have a 1.5:1 to 3:1 (horizontal : vertical) proportions.

   d. Build up first layer only to top of key pieces from first layer. Make sure the crest is level across the channel and water is pooling to this temporary crest elevation.

3. Build up subsequent layer(s) in 6″ to 12″ lifts, packing well with fine fill material until ponding water to its next temporary crest elevation.

> Repeat step 3 as many times as necessary to build up to design crest elevation.

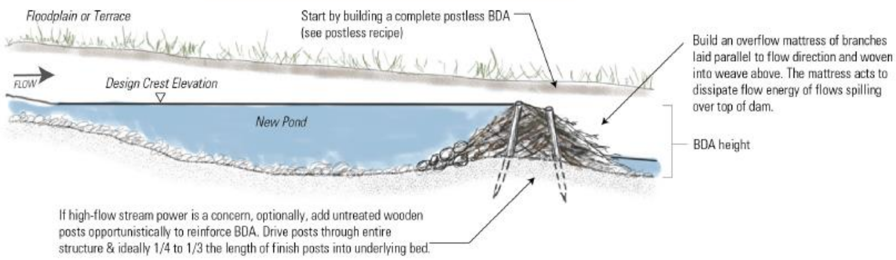
> Work a overflow mattress (laying branches parallel to flow) into dam on downstream side and build to provide energy dissipation to overtopping flows.

> If desired, and time permits, attempt to plug up BDA with mud and organic material (small sticks and turf) to flood pond to crest elevation. Optionally, you can leave this for maintenance by beaver or for infilling with leaves, woody debris and sediment.

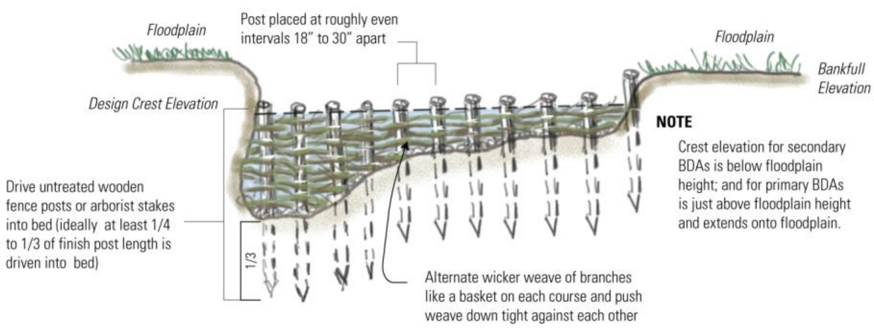
POST-ASSISTED BDA

- Posts can provide some temporary anchoring and stability to help with initial dam stability during high flows in systems with flashier flow regimes or that produce larger magnitude floods.
- For situations where additional support during high flows is deemed necessary, our suggested practice is to start out following the instructions to build a postless BDA, and then simply add posts as extra reinforcement after the fact.

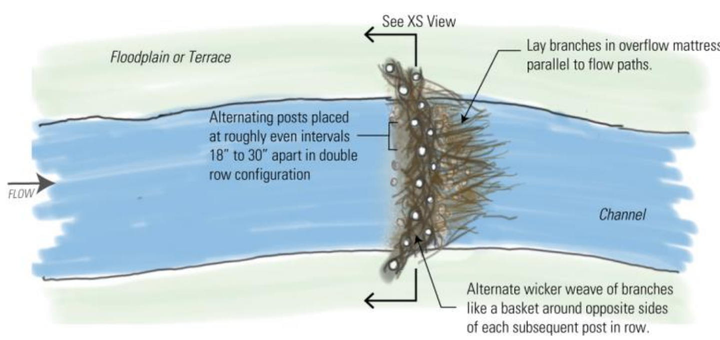
PROFILE VIEW WITH POSTS



X-SECTION VIEW



PLANFORM VIEW

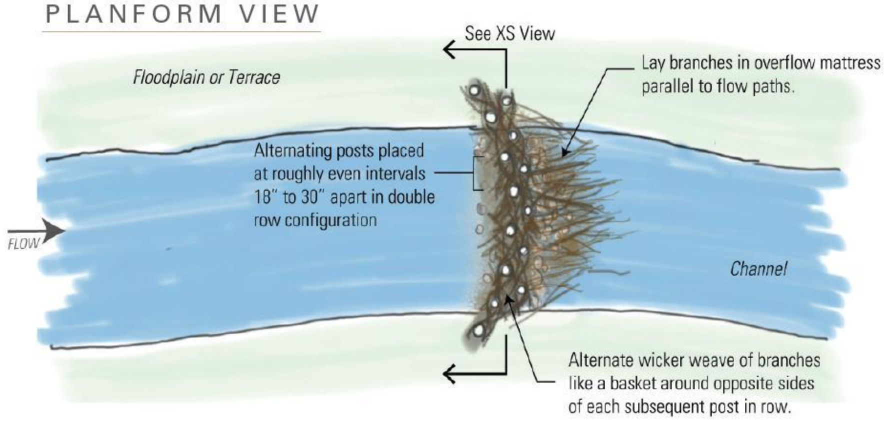


NOT-TO-SCALE

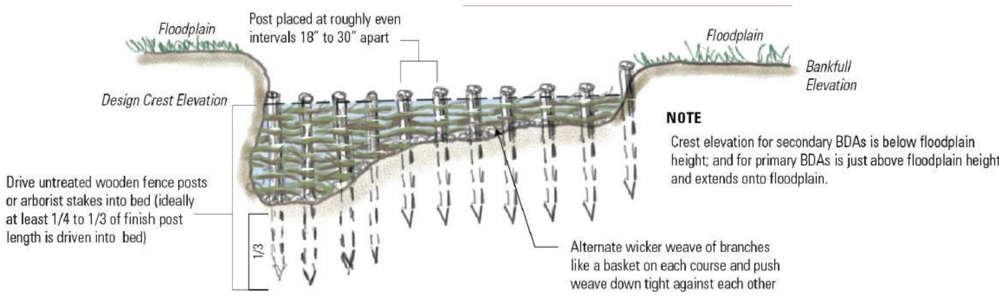
POST-LINE WICKER WEAVE

- BDAs can be constructed using post-line wicker weaves, to initially mimic beaver dam activity and later promote it.
- Posts used to layout a crestline, and long branches are woven between the posts to provide most of the structure.
- Post-line wicker weaves have been used for at least 150 years as instream structures, but have most often been used in check-dam or weir designs, which have higher crest elevations along the banks, and concentrate flow over the middle of the structure. By contrast, post-line wicker weave BDAs have a constant crest elevation as to not concentrate flow at any point.

PLANFORM VIEW



CROSS SECTION VIEW



PROFILE VIEW